Investigating Rock Mass Conditions and Implications for Tunnelling and Construction of the Amethyst Hydro Project, Harihari.

A Thesis

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Frontispiece

Entrance to the Amethyst Hydro Tunnel, completed 12-10-2012

Abstract

The Amethyst hydro project was proposed on the West Coast of New Zealand as an answer to the increasing demand for power in the area. A previous hydro project in the area was deemed unviable to reopen so the current project was proposed. The scheme involves diverting water from the Amethyst Ravine down through penstocks in a 1040m tunnel and out to a powerhouse on the floodplain of the Wanganui River. The tunnel section of the scheme is the focus of this thesis. It has been excavated using drill and blast methods and is horseshoe shaped, with 3.5x3.5m dimensions.

The tunnel was excavated into Haast Schist through its whole alignment, although the portal section was driven into debris flow material. The tunnel alignment and outflow portal is approximately 2km Southeast of the Alpine Fault, the right lateral thrusting surface expression of a tectonically complex and major plate boundary. The Amethyst Ravine at the intake portal is fault controlled, and this continuing regional tectonic regime has had an impact on the engineering strength of the rockmass through the orientation of defects. The rock is highly metamorphosed (gneissic in places) and is cut through with a number of large shears.

Scanline mapping of the tunnel was completed along with re-logging of some core and data collection of all records kept during tunneling. Structural analysis was undertaken, along with looking at groundwater flow data over the length of the tunnel, in order to break the tunnel up into domains of similar rock characteristics and investigate the rockmass strength of the tunnel from first principles. A structural model, hydrological model and rockmass model were assembled, each showing the change in characteristics over the length of the tunnel. The data was then modeled using the 3DEC numerical modelling software.

It was found that the shear zones form major structural controls on the rockmass, and schistosity changes drastically to either side of these zones. Schistosity in general steepens in dip up the tunnel and dip direction becomes increasingly parallel to the tunnel alignment. Water is linked to shear position, and a few major incursions of water (up to 205 l/s) can be linked to large (1.6m thick) shear zones.

Modeling illustrated that the tunnel is most likely to deform through the invert, with movement also capable of occurring in the right rib above the springline and to a lesser extent in the left rib below the springline. This is due to the angle of schistosity and the interaction of joints, which act as cut off planes.

The original support classes for tunnel construction were based on Barton's Q-system, but due to complicated interactions between shears, foliations and joint sets, the designed support classes have been inadequate in places, leading to increased cost due to the use of supplementary support. Modeling has shown that the halos of bolts are insufficient due to the >1m spacing, which fails to support blocks which can be smaller than this in places due to the close spacing of the schistosity.

It is recommended that a more broad support type be used in place of discreet solutions such as rock bolts, in order to most efficiently optimize the support classes and most effectively support the rock mass.

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Chapter 1

Introduction and Review of Current Knowledge

1.1 Background

With the recent boom in tourism and dairy farming on the West Coast, it has become important to secure the supply of power to residences in Southern Westland (Greymouth Star, 2010). Previously there was a power scheme on the Amethyst river at Harihari which was opened in 1954 and closed in 1980 (Greymouth Star, 2012). Following pre-feasibility investigation, it was found that reopening this scheme was not viable due to the cost of works needed to bring the infrastructure up to operational standards (Greymouth Star, 2010). For this reason a new scheme 1km north of the old scheme was proposed. Construction began in September 2010, and this is now nearing completion. The scheme (Figure 1-1) involves a tunnel connecting the Amethyst Ravine to the Harihari coastal plain and a 7MW power station which will have the capability of supplying power to 6000 homes (Greymouth Star, 2012).

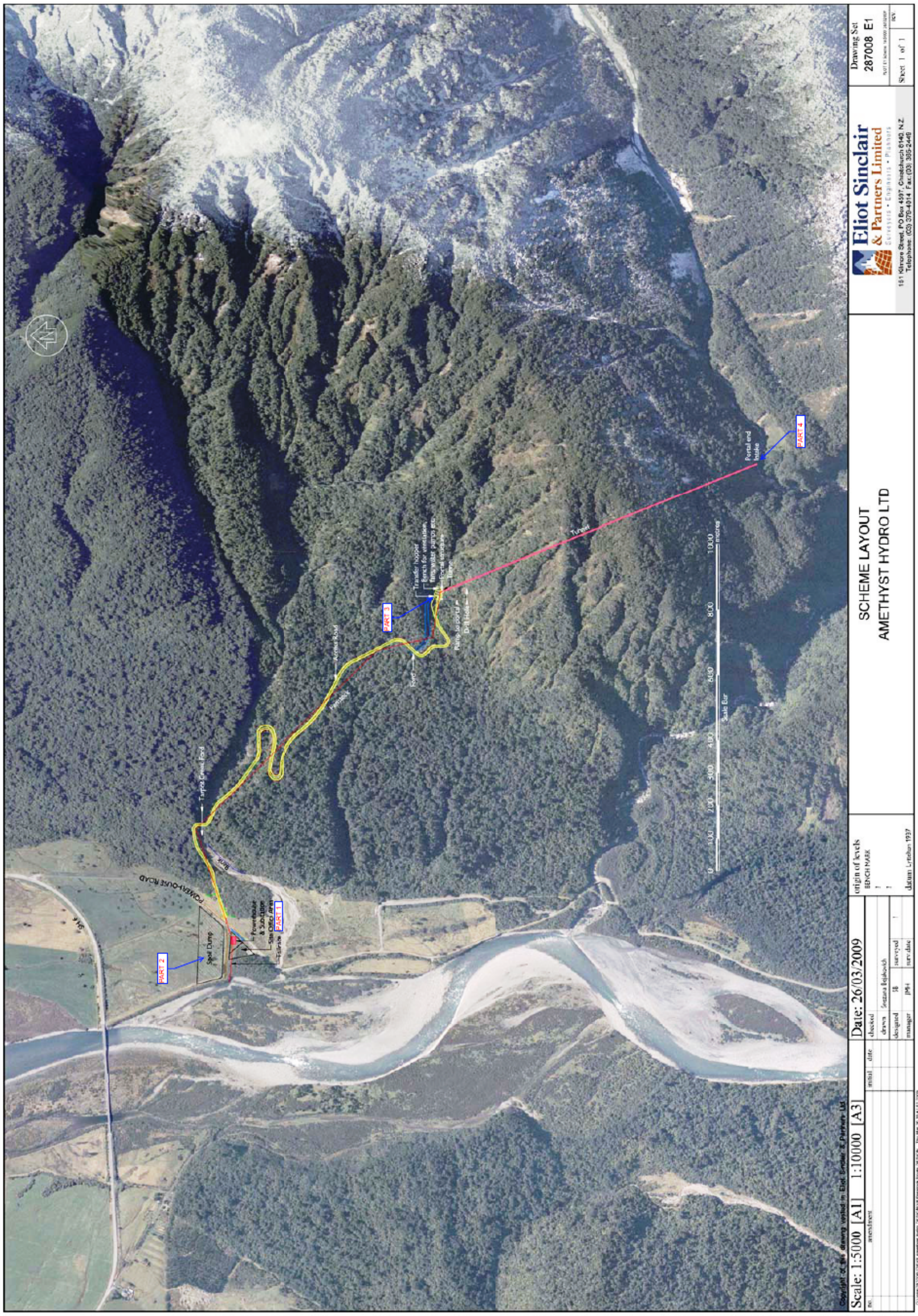


Figure 1-1: Proposed site layout for the Amethyst Hydro Scheme showing the tunnel (red), the portal access road (yellow) and the proposed position of the powerhouse. Penstocks can be seen as a red line approximately following the orientation of the access road (Eliot Sinclair & Partners Limited, 2009).

1.1.1 Area Demographics

The 2006 Census data indicates that the West Coast region has a population of 31,326 – 0.77% of the total population of New Zealand (Statistics NZ, 2006). The Westland District in itself has a population of 8,403 with 3,291 households. The projected populations for 2010 and 2031 are 8,880 and 8650, which is a 0.05 and 0.02% increase respectively from 2006 numbers (Statistics NZ, 2006). The West Coast region has 0.8% of the total occupied residences in New Zealand, 1.5% of the unoccupied residences and 1% of the total residences being built in New Zealand (Statistics NZ, 2006). A report published in 2001 on the increase and effects of tourism to the Westland region projected increases of tourism to the region in the following years (Simmons & Fairweather, 2001). Tourism is described as the one of the largest, if not the largest sector within the West Coast economy, and therefore securing the supply of power to the region is paramount (Moran, Simmons, & Fairweather, 2001).

1.2 Thesis Aims

The project has experienced delays in advance rate due to a number of factors, both geotechnical and otherwise. The aim of this thesis is to build an engineering geological model of the site and investigate the geotechnical ‘surprises’ that arose during production. These included blocky ground, large shear zones and high water pressures. Numerical modelling will be used to investigate how the rockmass is behaving and how the support classes could be optimized within the particular rockmass. This will allow for an assessment of the geological factors controlling rockmass characteristics and the problems faced during construction. The site is also very close to the Alpine Fault, and it is important to ascertain what effect that has on the rock characteristics and the problems faced during construction. This information will be useful for any future tunneling projects in similar ground and/or similar geotechnical conditions.

1.3 Study Area

1.3.1 Site Location

The Amethyst Hydro Project is located approximately 7km North of Harihari on the north bank of the Wanganui River (Figure 1-2). The tunnel is located on Department of

1-2: Area map of the South Westland region showing the location of the tunnel (red star) in relation to Hokitika (top right of map) and Franz Josef (bottom left of map) (Google, 2012).

Conservation (DoC) estate. The exit portal (west) is at 298m above sea level and the tunnel rises from this elevation at a grade of 1:4.4, on an orientation of 156^{o} relative to north (in plan view). The total length is 1058m long. The intake portal (east) is located in the Amethyst Ravine at an elevation of 502m. The coordinates for the position of the intake are: 43^{o}09'53. 26" S 170^{o}38'30. 02" E.

1.3.2 Site History

Although a nearby hydro-electric scheme was in operation until 1980, the site of the current power scheme had no previous history of power generation or other activity (Greymouth Star, 2010). Before the proposal of the Amethyst Hydro Scheme, the site was primarily used by hunters and the ravine was infrequently used for water sports such as kayaking (Greymouth Star, 2010).

1.3.3 Delays to Production and Current Status of the Project

Currently, the tunnel portion of the scheme has been completed, and the intake and penstocks are under construction. During tunnel construction, advance rate varied substantially, depending on the ground conditions, the groundwater content and flow rate, and other factors such as machinery breakdowns and maintenance (power outages due to lines maintenance). Original commencement of tunneling was also delayed by changes in portal position and the subsequent need to reevaluate the portal rock mass/debris flow characteristics. Construction on the powerhouse is well underway and the aim is to have the scheme operational by the deadline of late March 2013.

1.3.4 Rainfall Data

Rainfall on the West Coast is generally high, and the area had an average annual rainfall of approximately 2900mm between 1981 and 2010 (NIWA, 2010).

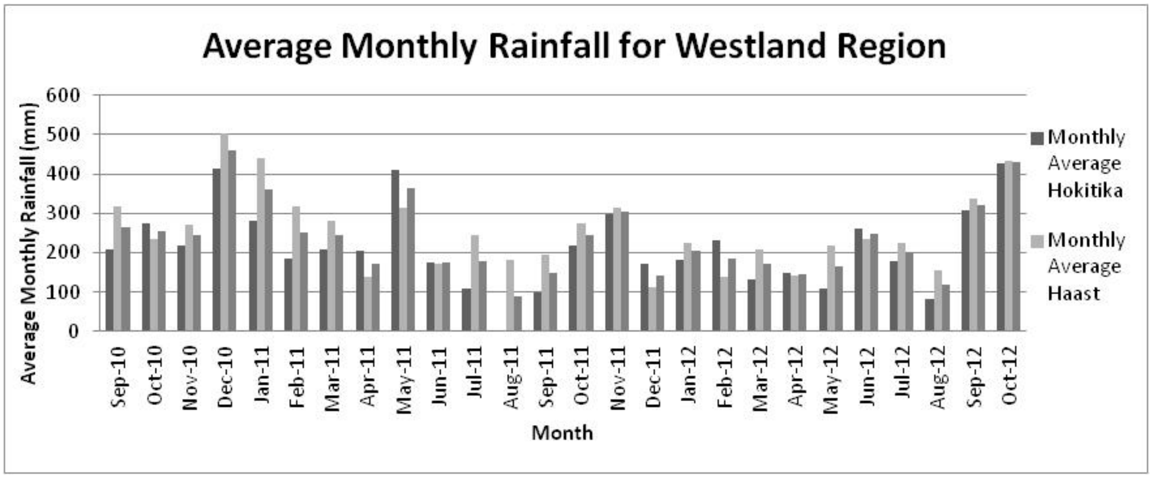


Figure 1-3: Chart showing average monthly rainfall for the Westland region during the period of tunnel construction. Data was collected at Hokitika Airport and in Haast, so for Harihari the actual rainfall amount will be somewhere between the two values (MetService, 2012).

1.4 Geological Setting

1.4.1 Regional Geology

New Zealand's position on a subducting plate boundary setting is very important in this field area as the surface expression of the plate boundary – the Alpine Fault – lies very near the west portal (Figure 1-4). The geology of the South Island of New Zealand is very much influenced by the tectonics relating to the plate boundary setting and the rocks encountered in the region reflect these collisional tectonic movements. These rocks include the Haast Schist group, which is commonly known by the informal term of Alpine schist in this region. It is into this Alpine schist that the tunnel was driven.

The Alpine schist is a metamorphic rock, a direct result of the plate boundary scale tectonics. Most of the uplift and deformation of the Alpine schist sector of the Haast Schist group is thought to have occurred during the early and mid Jurassic period (starting approximately 206 million years ago), within the Rangitata Orogeny period of crustal collision (Adams, 1979).

Presently, the region experiences extremely fast rates of uplift and exhumation, the bulk of which has occurred since the Kaikoura orogeny (approximately 25km in the past 10 million years (Cooper, 1980)), which in turn leads to a very dynamic geomorphological setting (Coates, 2002). In accordance with this various debris flows, rock avalanches and other such terrestrial mass movement processes are common in the landscape. This geological environment has implications for the Amethyst project, through the dynamic setting and mass movements that may occur. These may impact the project itself or cause blockages of lifelines such as closing the portal or access roads. The rate of uplift in the region also makes it prone to earthquakes and higher stress, which has an impact on the rock mass tunneled through.

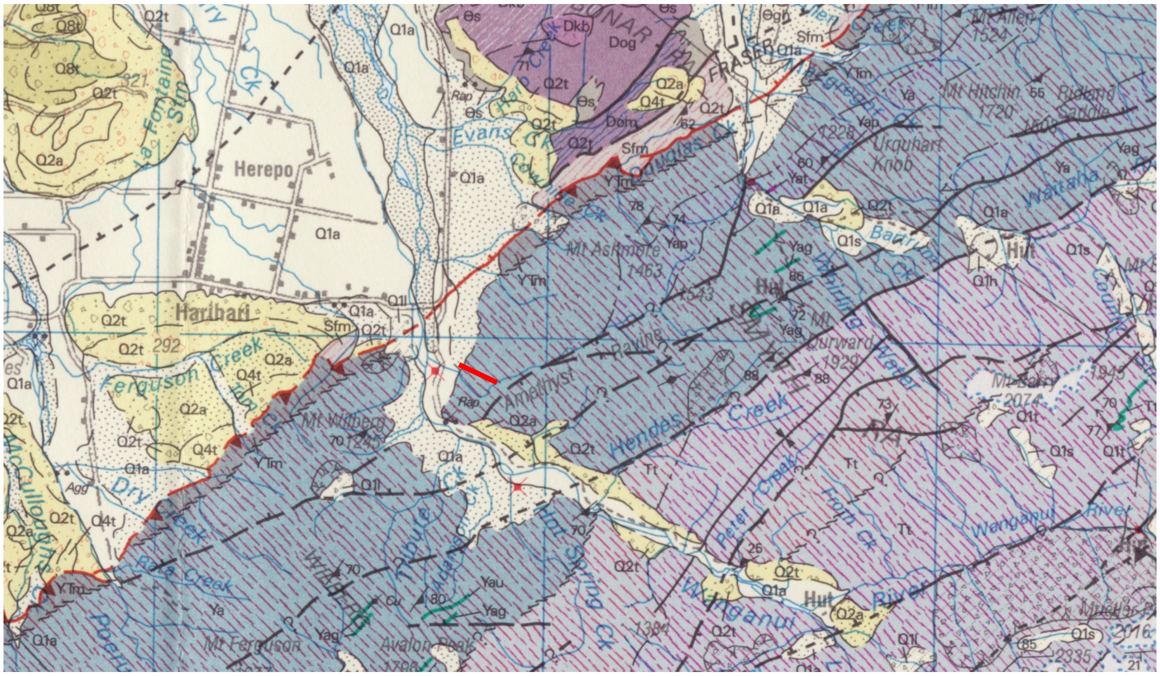


Figure 1-4: Local area geology showing the position of the tunnel (bold red line) relative to the Alpine Fault (red dashed line). The tunnel traverses Alpine schist and some debris flow at the west portal (Cox & Barrell, 2007).

1.4.2 Site Geology

The Hydro scheme is located in Alpine schist, approximately 1-2km from the Alpine Fault. This leads to a number of implications for the strength and overall characteristics of the rock mass. Proximity to the Alpine Fault may lead to decreased strength within the rockmass itself due to higher local stresses, or indirect rock mass strength loss through features such as faults or shears near the fault. The fault may also provide a conduit for fluids in the area which could weaken or alter the rock mass.

The section of Alpine schist found in the field area is one of the westernmost sections, and can be correlated to the Aspiring lithologic association, which in turn is a subdivision of the Rakaia terrane (Cox & Barrell, 2007). There is no definite depositional age for the protolith of these rocks, but a Permian age has been arbitrarily assigned (Cox & Barrell, 2007). Deformation and metamorphism took place during the Rangitata Orogeny, as with the entire Haast Schist group.

According to Cox and Barrel (2007), the Alpine schist in this region is within the oligoclase amphibolite metamorphic zone at the portal end of the tunnel and grades into the garnet amphibolite zone nearer the intake end. The tunnel is in textural zone 'IV' of the Alpine schist, which is described as follows:

Rocks have prominent light and dark coloured quartzofeldspathic and micaceous segregation layering. Primary sedimentary structures and clastic grains are destroyed at mm-cm scale, although primary sedimentary protoliths may be represented in outcrop by compositional variation. Schistosity tends to be irregular due to porphyroblast growth. Metamorphic mica grain size is 0.125-0.5 mm. Schistosity and segregation are ubiquitous and rocks are termed schist. Quartz veins are abundant in most lithologies. (Cox & Barrell, 2007).

The rock within the tunnel followed this description closely (see Figure 1-5), with variable thicknesses of quartz banding.

Figure 1-5: Left wall of the tunnel at approximately 750m showing a typical section of schist. Rock is wet, so more difficult to see the lighter layers and banding. Larger quartz band just above the ruler. White ruler for scale is 25cm.

1.4.3 Site Geomorphology

Geomorphological factors influence the site geology and could potentially have an impact on the stability and long-term design life of the tunnel.

1.4.3.1 Mass Movements

Mass movement processes such as rock avalanches and debris flows are common occurrences in the area due to the steep terrain and high rainfall volumes.

Earthquake triggered mass movements are a risk in this region due to the number of nearby faults and their ability to produce large earthquakes. The Mt Wilberg avalanche is thought to have occurred due to an Alpine Fault earthquake before 1300 AD and has an estimated volume of $40x10^6m^3$ (Chevalier et al. 2009). It is thought to have dammed the Wanganui River briefly, but deposits can still be identified in river terraces. In identifying the avalanche deposit, Chevalier et al. (2009) also note that due to the rugged terrain and high rainfall of the area, such mass movement deposits are often short-lived, meaning their hazard and recurrence rate may be easily underestimated. Mt Wilberg is directly West across the Wanganui River from the Amethyst Hydro Project site, and so this in particular shows the importance of recognising this type of hazard for the project site.

Due to the high level of rainfall in this region, the risk is exacerbated that rainfall triggered mass movements could occur. These mass movements would have the ability to obscure the tunnel portal or other areas of the project, and have been taken into consideration during the feasibility stages of the project. This is partially what influenced a last minute alignment change of the tunnel and re-positioning of the portal. It was found that the original location had a high risk of debris flow above it, which could potentially obscure the portal. The new location was within debris flow deposits for the first approximately 70-100m. This shows there have been mass movement events previously even in this new location, and these could occur again.

1.4.3.2 Earthquakes

The Alpine Fault is a significant factor of the geomorphological processes active within the area surrounding the Amethyst Hydro Project. This is due to its ability to produce a large magnitude earthquake event with significant shaking which could provide the potential for ground failures or mass movements in or around the Amethyst Hydro Project, as demonstrated with the Mt Wilberg avalanche (Chevalier et al., 2009). Any surface ruptures may also have an impact on the powerhouse and penstock outlet as the Alpine Fault runs very close to the proposed location of these. Large ruptures could also have an effect on the operation of the scheme, as the coast could be cut off from services such as power and accessibility could be reduced in the event of such a rupture.

Earthquakes in general could be generated from any of the numerous faults in the nearby region. As can be seen in Figure 1-4, faults are a common feature of the landscape. The main contender for producing a large earthquake is the previously mentioned Alpine Fault, but other large faults such as the Fraser Fault could also have potentially damaging impacts on the site (Rattenbury, 1986). The Fraser Fault passes near Harihari to the West between the Alpine Fault and the coastline (Young, 1968). While fieldwork was taking place, two small earthquakes (<5M) were felt. These included:

- 3.9M, 20km East of Harihari at a depth of 5km on 27/4/2012
- 4.2M, 10km South of Ross and 30km North East of Harihari at a depth of 15km on 6/5/2012 (GNS Science, 2012)

Portal stability and the resilience of other infrastructure associated with the scheme would be of concern in a significant seismic event.

1.4.3.3 Warm Springs

Warm springs are found in the Wanganui River immediately to the east of the Alpine Fault. The water is of sodium-bicarbonate composition and flow rates appear to be rainfall related (varying seasonally) (Cox & Barrell, 2007). These springs have a distinct smell due to the discharge of hydrogen sulphide gas and are the surface expression of fluid flow within the steep geothermal gradient caused by rapid uplift along the Alpine Fault (Cox & Barrell, 2007). These springs are thought to be related to the Alpine Fault and demonstrate the effect of the fault on the hydrogeology of the rock mass. These springs could also potentially be related to high inflow rates observed within the tunnel. The chemistry of the springs may have an impact on the strength of the rock, causing rock in the vicinity of the springs to break down or be weaker than the surrounding rock mass.

1.4.3.4 Hydrogeology

Although average annual rainfall in the area is high, this has not had a significant impact on the site. The groundwater encountered during tunneling mainly related to clay bands and areas of perched water table. Although water has varied throughout the tunnel, this does not seem to be influenced by periods of increased rainfall. Additionally, the rock cover has been 200-400m for the majority of tunneling, and this would create a buffer and a delay to rainfall entering the groundwater system (Wahlstrom, 1973).

1.5 Previous Work and Tunnel Design

Prior to investigations undertaken for this thesis, work had been compiled in the pre-feasibility and feasibility stages of the hydro project.

- GNS Science (formerly NZ Geological Survey) undertook work in the area from 2000 for work on the Aoraki region of their QMap series (1:250,000 scale geological map series of New Zealand) (Cox & Barrell, 2007).

- Boffa Miskell undertook a visibility assessment in the area to assess how much of the project would be visible from various viewpoints along SH6. It was found the project would generally not be visible from the road (Boffa Miskell Ltd, 2007).

- Geotech Consulting Limited started drilling and site investigation in 2006 following a pre-feasibility study into the area. The summary of the drilling investigation showed expected ground conditions, hydrological conditions and the overall expected orientation of major structural features within the tunnel (Geotech Consulting Limited., 2006).

- Aurecon New Zealand Limited (2009) prepared a report on ground conditions, based on drill logs and summary of drilling documents, which had been prepared by Geotech Consulting Limited.

- A final tunnel design and support class system was established in 2008 by URS New Zealand Limited (see Figure 1-6).

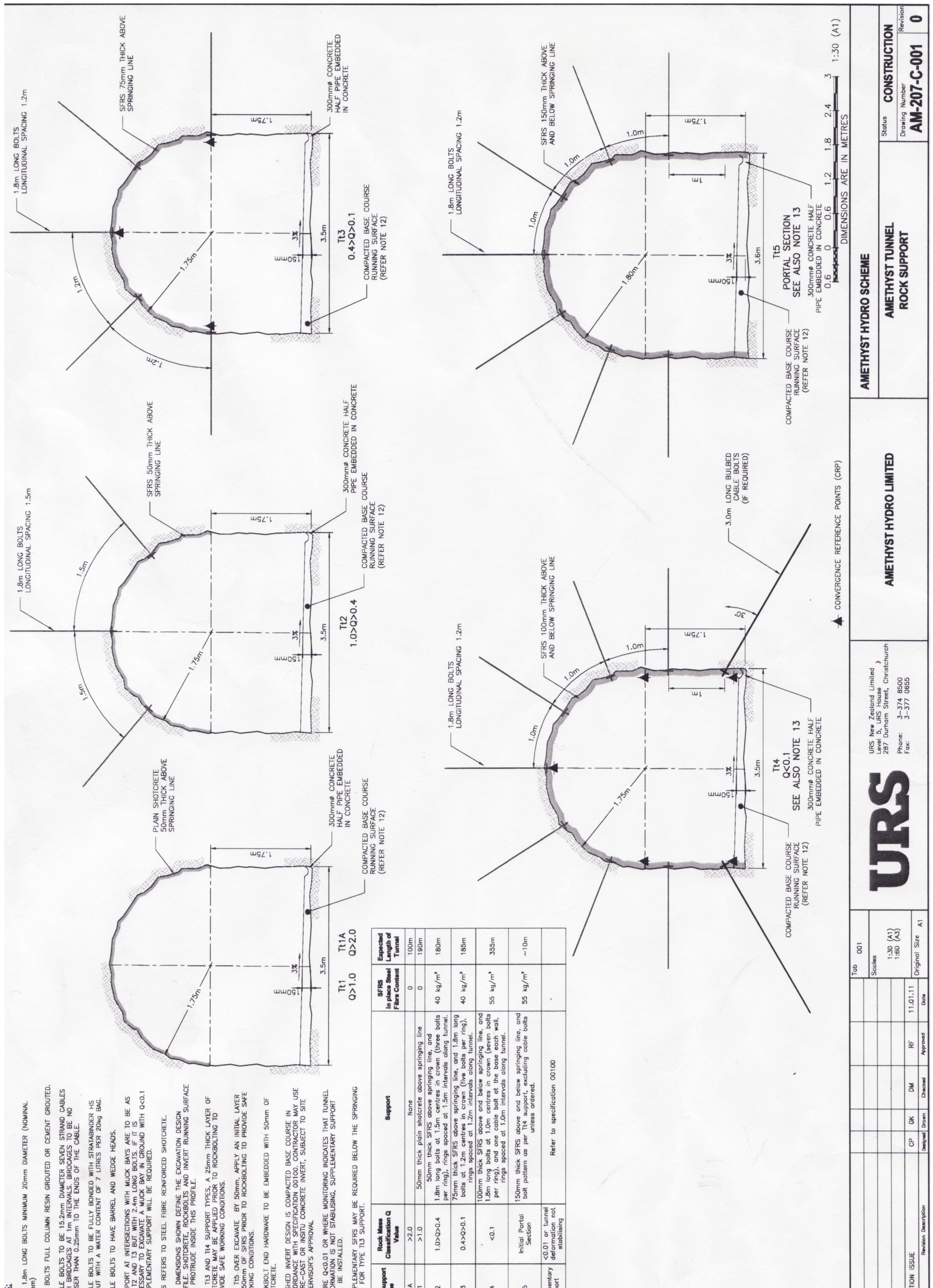


Figure 1-6: Final design and support classes for the Amethyst Hydro tunnel (URS New Zealand Limited, 2008).

The area has also been host to research undertaken on the Alpine Fault and other key geomorphological features of the area as mentioned in Section 1.4.2, such as the Mt Wilberg avalanche (Chevalier et al., 2009) and the Fraser fault (Young, 1968).

1.6 Thesis Objectives

The principal objectives of this thesis are:

1. To carry out an engineering geological field investigation to determine relevant geotechnical and engineering geological parameters for the Amethyst Tunnel. Scanline mapping of the tunnel length, along with re-logging of exploratory boreholes and strength testing of rock samples to give quantitative data which may be used for stability analyses.
2. To nominate structural domains within the tunnel for numerical modelling. The orientations of geological features (shears, schistosity, and joints) within the rock mass are the most important features in the assessment of tunnel stability, through both block geometry (shape and size) and through the nature of instability (i.e. block failure versus ravelling). By calculating mean orientations for different structural features, it is possible to predict representative failure types kinematically and to numerically model these.
3. To assess the effect on the rock mass of the nearby Alpine Fault and any changes in the geometry of structural features or rock mass conditions with increasing distance from the fault.
4. To numerically model the representative structural domains present in the tunnel and analyse the stability of these, to assist in the optimisation of support.
5. To provide recommendations to optimise support and assist in planning of future projects in similar rock or geotechnical conditions.

1.7 Thesis Organisation

Following this introductory chapter:

- Chapter 2 outlines and discusses the engineering geological and geotechnical field and laboratory program. Testing procedures, field practices and summarized results are discussed.
- Chapter 3 develops the engineering geology model for the tunnel by investigating the geotechnical parameters and specific characteristics of the rock mass identified in the preceding chapter and data obtained from defect orientation analysis.
- Chapter 4 includes the results of 3D distinct element numerical modelling, analysing possible failure mechanisms and ways to optimise support.
- Chapter 5 summarises the main findings of the thesis, provides conclusions regarding failure mechanisms and demonstrates how the main aims of the thesis have been fulfilled.

Chapter 2
Engineering Geological and Geotechnical Investigations

2.1 Introduction

The principal aims of this engineering geological investigation have been to provide geotechnical input data for the development of an engineering geological model of the Amethyst Hydro Tunnel. Fieldwork was undertaken during the final six months of tunnel construction. It involved an extended period of scanline mapping of the tunnel and re-logging of core drilled prior to the start of construction. Samples were also collected during the fieldwork stage for later strength testing. In conjunction with scanline mapping, the tunnel was classified according to both the Q-system (Barton et al., 1974) and the RMR_{89} (Bieniawski, 1989).

2.2 Field Investigation

2.2.1 Introduction

Field investigation was undertaken on site at the Amethyst Hydro Project during the months of March-July 2012. The tunnel was in construction while this was occurring, so data was obtained mostly within a few months of the rock being exposed. Investigations included both scanline mapping of the tunnel and logging of core that had been drilled during the pre-feasibility stage of the project.

2.2.2 Engineering Geological Mapping

2.2.2.1 Discontinuity Measurements

Scanline mapping was undertaken in accordance with NZ Geotechnical Society guide to describing soil and rock (NZGS, 2005). Some alterations to this scheme were made due to the need for input parameters needed for the program JointStats ("JointStats," 2000) and future numerical modeling in 3DEC (Itasca Consulting Group Inc., 2010). Scanline mapping occurred along the length of the tunnel, at the height of the services (water pipes and electricity) running along the east wall (approximately 1.5m above the invert). This was mainly undertaken along the east wall due to increased exposure of the rock in this wall (due to the strike of the schistosity, the right wall usually had shotcrete to a lower level) and due to the location of man bays. Where the east wall was unavailable, the right wall was used, although due to the oblique strike of the schistosity, care was taken not to re-measure the same structures twice at different intervals along the scanline when switching between walls (see Figure 2-1).

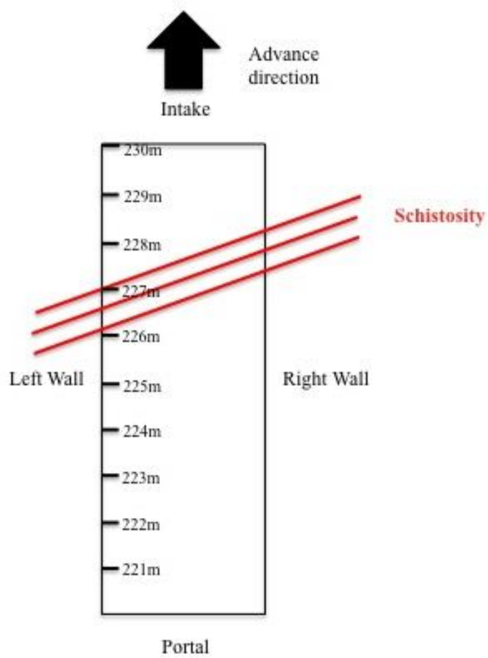


Figure 2-1: Diagram showing tunnel in plan view. Structures were primarily measured on the left wall, but due to obliquity of the dip direction, care had to be taken not to remeasure the same structure if for some reason the right wall was used.

A measuring tape was laid down for chainage and this was marked on the tunnel walls at 50m intervals. Individual discontinuity measurements were taken wherever an appropriate and surface was available to be measured (i.e. not covered in shotcrete or blast damaged). Ultimately, it was endeavored to take an individual discontinuity measurement at least every metre. Often blast damage, shotcrete, build-up of precipitate or other factors meant joints could not be measured. Due to the continuous nature of the foliation, schistosity measurements were only taken once every metre, and changes in the continuity of this were noted in the comments of the geological log. Schistosity spacing was also noted for the RMR_{89} classification measurement, which provided a spacing value for numerical modeling. Likewise, recurring joint sets were usually measured at realistic intervals, noting that too fine a scale was impractical due to time constraints with ongoing tunneling (and restricted access to the tunnel during certain cycles of the tunneling process) and too coarse a scale would result in an insufficient data set. Again, measurements for RMR_{89} gave defect spacing changes along chainage, and these values were used for modeling, without the need to measure every parameter for every joint surface.

The following attributes were recorded for each discontinuity according to the input requirements for future statistical analysis using the JointStats program ("JointStats," 2000).

- Chainage – the point the joint surface crossed the scanline. This was taken in relation to the measuring tape along the wall but was the point where the joint crossed the scanline at 1.5m up the tunnel wall.
- Dip and dip direction – obtained using a compass in the method prescribed by the ISRM guidelines (ISRM, 2007).
- Trace length above and below the scanline and in total – measured as far as the discontinuity surface could be seen within the tunnel (visibility often obscured by shotcrete above 1.75m) .
- Type – constrained to joint, shear or schistosity. Some shears infilled with lower strength material ran along joint or schistosity orientations but were classed as 'shears' due to the larger impact on overall stability the low strength fill had than schistosity or joints that weren't infilled.
- End point class – This attribute described whether the ends of the discontinuity could be seen within the tunnel. The schistosity was mostly all fully censored, as it is a continuous plane throughout the rock mass and therefore discreet endpoints couldn't be seen within the confines of the tunnel. Some joints were classed as 'censored above' or 'censored below' if the end point could be seen. Some were also uncensored meaning the end points of the joints could be seen both above and below the scanline.

- Top and Bottom terminations (if present) – the recorded observation of what medium the joint terminated in or beneath which could no longer be seen (shotcrete, intact rock, schistosity).
- Roughness – Logged according to the NZGS guide to describing soil and rock (NZGS, 2005), observations included 'Slickensided', 'Smooth', and 'Rough'. 'Very Smooth', 'Slightly Rough' and 'Very Rough' were also added in in coordination with the RMR_{89} classification values (Bieniawski, 1989).
- Aperture – Classified as the 'mean perpendicular distance between adjacent rock walls of a discontinuity' (NZGS, 2005). A measurement in millimetres (mm) of the thickness of infill or the distance between sides of the discontinuity was taken.
- Infill – Logged according to the NZGS guide to describing soil and rock (NZGS, 2005). Attributes were based on observed infill i.e. 'Clay', 'Quartz', 'Sandy' or 'Clean' if no infill was present.
- Jr value – based on Barton's Q-system values for joint roughness values – takes into account both the roughness and large-scale waviness of the joint (Barton et al., 1974).
- Large scale planarity – planarity of discontinuity over metre scale in accordance with the NZGS standard (NZGS, 2005).
- Comments – anything else worth noting about the discontinuity or general tunnel conditions.

One bias taken into account while scanline mapping was the occurrence of any joints that did not intersect the scanline. Some joints were oriented parallel to the tunnel and may not have intersected the scanline in the areas where they were having the most effect on the rock mass stability and overall characteristics. In these areas, measurements of the joints were taken even though they fell outside the scanline. In the data set, these joints are included, and are used for spacing and persistence measurements. They are present in the rockmass and would overestimate block size if left out of these calculations simply because they don't appear on the scanline.

Full shotcrete to the floor of the tunnel was encountered in places, and this meant that little to no measurements could be recorded from these sections. Increased shotcrete was associated with decrease in rock quality due to presence of shears, decreased block size, decreased RQD, increased water inflow, or a combination of factors. Shotcrete was also applied liberally where the tunnel widened for any reason (man bays, muck bays, transformer bays), especially where vital services were located and where failure of the tunnel would have the biggest impact. In these areas general descriptions of the rock mass were obtained, although often these may not have been accurate. In these areas, data was used as logged by the site Engineering Geologist (Smith, 2011). The attributes recorded by Smith (2011) were only those that directly related to obtaining the Q-system value, as per the contract, and because of this, the exact orientations and other attributes of some shears were unable to be obtained. Some important stability-controlling shears had been fully covered in shotcrete by the time of scanline mapping, so were not visible for full description.

2.2.2.2 Rock Mass Classifications

The rock mass was classified by two methods – Barton's Q-system (Barton et al., 1974) and the Rock Mass Rating system (Bieniawski, 1989). Rock mass classification ratings were analysed for both classification systems every 5m providing the rock was visible, and were analysed (or calculated) at smaller intervals if a significant change in the rock occurred. Values were intended to be an overall average of the rock 2.5m to either side of the actual chainage noted down. This means that often the 'worst case scenario' measurement was noted in the interest of making a conservative estimate of rock mass strength conditions. In order to most accurately classify the rock mass, this approach was not used if this 'worst case scenario' was an obvious outlier that would not affect the rock quality for the whole 5m interval being represented.

2.2.3 Core Logging

Although the core had previously been logged by Geotech Consulting, BH1 was re-logged in conjunction with NZGS guide to description of rock and soil (NZGS, 2005), with the aim of cross-checking the observations made in the original log with any observations made during scanline mapping. The original orientation data for the core was unavailable, so actual orientations of the discontinuities within the core were unable to be re-measured. RQD, roughness, infill, alteration, weathering, strength and other general observations were obtained from the core. Due to the time lapse between drilling and re-logging (the core was drilled originally in 2006 and was re-logged in July 2012), it is likely that structures such as clay shear zones had lost some of their original characteristics through drying and other atmospheric-induced changes. Due to time constraints on fieldwork, only BH1 was able to be re-logged. The other holes were cross-checked using photo data from the original core, although it is to be noted that this method was undesirable and produced less accurate data and results than proper core logging would achieve.

2.3 Laboratory Testing

2.3.1 Introduction

Laboratory testing was undertaken according to the International Society for Rock Mechanics (ISRM) guidelines (ISRM, 2007). Testing included strength and seismic velocity tests. In most cases, testing with foliation direction both parallel and perpendicular to stress direction/wave propagation direction was undertaken (see Figure 2-2). However, due to limited sample size in some cases only limited testing could be achieved.

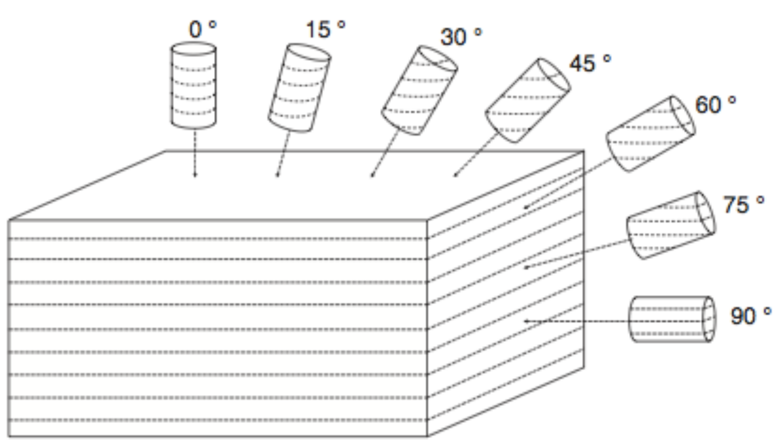


Figure 2-2: Diagram showing coring angle of sample relative to foliation. 0^o is referred to as 'perpendicular'; 90^o is referred to as 'parallel' to stress direction/wave propogation direction. Samples were cut/cored as close as possible to 0^o or 90^o (Kim et al., 2012).

2.3.2 Sample Collection

Samples were collected from the tunnel walls and muck piles during field investigations between March and July 2012, and analysed in the University of Canterbury Rock Mechanics laboratory in October. Samples were taken from the walls of the tunnel anywhere where loose blocks could be removed without compromising the stability of the walls.

The original intention was to collect a wide range of samples at varying chainage up the tunnel and create a realistic synthesis of the overall intact rock strength. Unfortunately, due to scaling procedures during tunnel construction, there was not a large amount of loose rock in the walls, and therefore few samples were collected overall. These chainage-recorded samples were used for point load testing (PLT) to gain strength measurements. Sample size was limited by defect spacing, so it was difficult to obtain samples large enough to core the required length to width ratio for testing unconfined compressive strength (UCS). Due to blasting, these samples may have had micro-fractures within them, which may invalidate any strength data obtained. There was a degree of bias in the samples obtained; they were only taken from areas with relatively low amounts of shotcrete, meaning the rock mass is most likely stronger here, leading to an overestimation of the overall intact strength. However, it is likely that exceptionally strong rock was also not sampled as this tended to form more intact walls and therefore no representative blocks could be taken. The locations of samples are shown in Figure 2-3.

Samples used for UCS testing were taken from the muck pile after blasting (face at 920m at this point). This was to determine a representative correlation for the rock mass between UCS and PLT results. This correlation was then used to reliably estimate strengths of the chainage-recorded samples after only point load tests had been conducted. The bias with these samples is that larger blocks were taken in order to achieve the required distance to width ratio of core for testing. It could be expected that these larger blocks were generally at the stronger end of the rock strength spectrum throughout the tunnel, and therefore were more intact and able to form larger blocks after blasting.

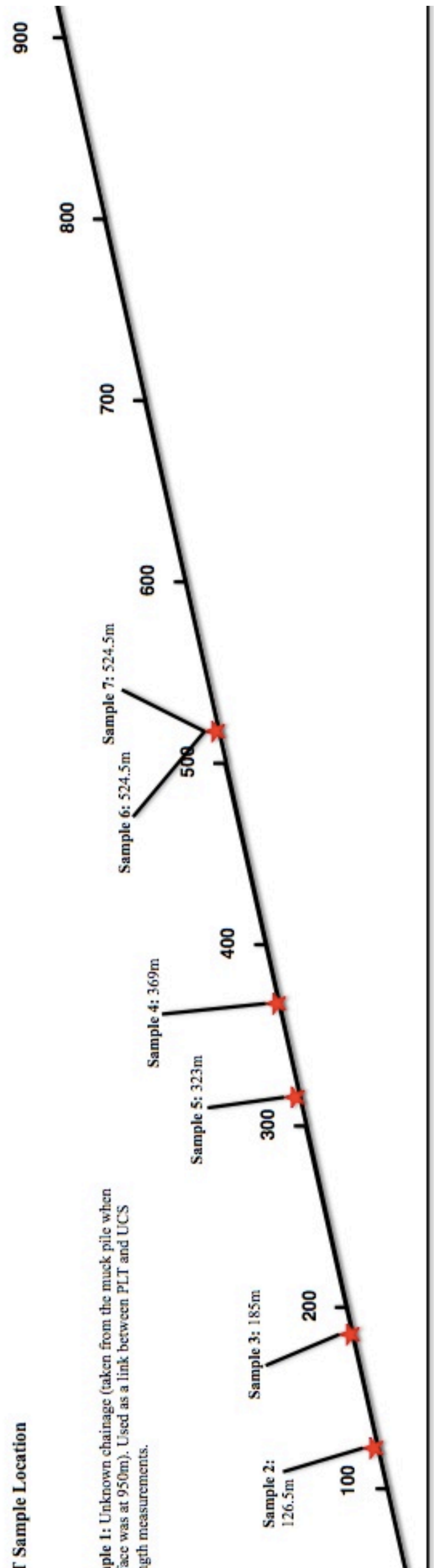


Figure 2-3: Location of samples used for point load testing. UCS samples were picked out of the muck pile (due to size requirements) when the face was at 950m.

2.3.3 Seismic Velocities

2.3.3.1 Introduction

The seismic velocities of a rock can be used to calculate the rock's dynamic properties, including the elastic modulus and Poisson's ratio. Because they are non-destructive, P and S wave velocity tests were conducted on core samples before UCS testing commenced. Seismic velocities were determined in accordance with ISRM guidelines (ISRM, 2007).

2.3.3.2 Results

Samples had varying dimensions and were of varying foliation orientations relative to the wave propagation direction. Only sample 1 produced a viable result due to the level of background noise present during the testing of samples 2, 3 and 4.

Table 2-1: Summary results of seismic velocity testing undertaken on core samples taken from the muck pile when the face of the tunnel was at 920m.

SAMPLE ID	FOLIATION RELATIVE TO STRESS	P-WAVE VELOCITY	S-WAVE VELOCITY	YOUNG'S MODULUS	POISSON'S RATIO
Sample 1	Parallel	4162	2638	42.94	0.164

2.3.3.3 Discussion

Unfortunately due to the level of background noise within the building during testing, only one of these tests returned a viable result. For this reason it has been impossible to correlate results and get a reliable average for the rock mass. Instead, this one result has been relied on. In reality the rock mass varies slightly in strength and weathering throughout the length of the tunnel and this one test result therefore may not be representative of the intact strength for the entire rock mass.

The successful test had the foliation orientation parallel to seismic wave propagation direction (Figure 2-2). As demonstrated by Kim et al. (2012) on the Yeoncheon schist, core tested with foliation orientation perpendicular to wave propagation direction exhibited lower seismic velocities than core tested parallel to wave propagation direction. This shows that the parallel test undertaken on the intact rock exhibits a higher velocity than would be calculated for the rock mass as a whole, in addition to the higher value produced by the orientation of the foliation. This means the calculated Young's modulus and Poisson's ratio may also be overestimated. This is therefore a best-case estimate of the seismic velocity parameters of the rock mass. It has been found that based on sample diameter and rock type, there may be a correlation between higher P-wave velocities with larger diameters. This may also have impacted the validity of the Young's modulus and Poisson's ratio, but as these tests were conducted on samples with the same diameter, this will only be an issue if future testing is undertaken with different sample sizes (Fener, 2011).

2.3.4 Unconfined Compressive Strength

2.3.4.1 Methodology

Tested according to the ISRM guidelines (ISRM, 2007), UCS tests were undertaken on large muck samples as explained in section 2.3.2. Block size was controlled by the schistosity as samples tended to break along these planes. Due to the spacing of the schistosity, the block size of the rock mass was too small to have the recommended height to diameter ratio of 2.5-3.0 (50mm platens used). In addition, the rock was prone to 'discing' during coring (when coring perpendicular to schistosity plane orientation) which further decreased the length of core available. For this reason only 4 tests were undertaken. Another problem existed where the core ends were not perpendicular to the sides due to the core being drilled not quite perpendicular to the schistosity. To address this swivel-platens were used, and this may have had an effect on the final measured compressive strength.

Tests were undertaken both parallel to schistosity and perpendicular to schistosity in order to obtain maximum and minimum strengths.

2.3.4.2 Summary Results

Although only one test was undertaken with foliation parallel to stress direction, it can be seen in table 2-2 that the rock is much weaker along this orientation. Tests undertaken with foliation perpendicular to stress direction gave a higher stress result.

Table 2-2: Summary results of UCS testing on Alpine schist of varying orientation, taken from the muck pile when the face of the tunnel was at 920m.

SAMPLE ID	FOLIATION RELATIVE TO STRESS	WIDTH/DIAMETER RATIO	FAILURE LOAD (kN)	STRESS (MPa)
1	Parallel	2.25	93.1	48.0
2	Perpendicular	1.85	112.1	57.8
3	No foliation orientation (pure quartz sample)	1.85	78.3	40.4
4	Perpendicular	1.71	131.6	67.8

2.3.4.2.1 Sample 1

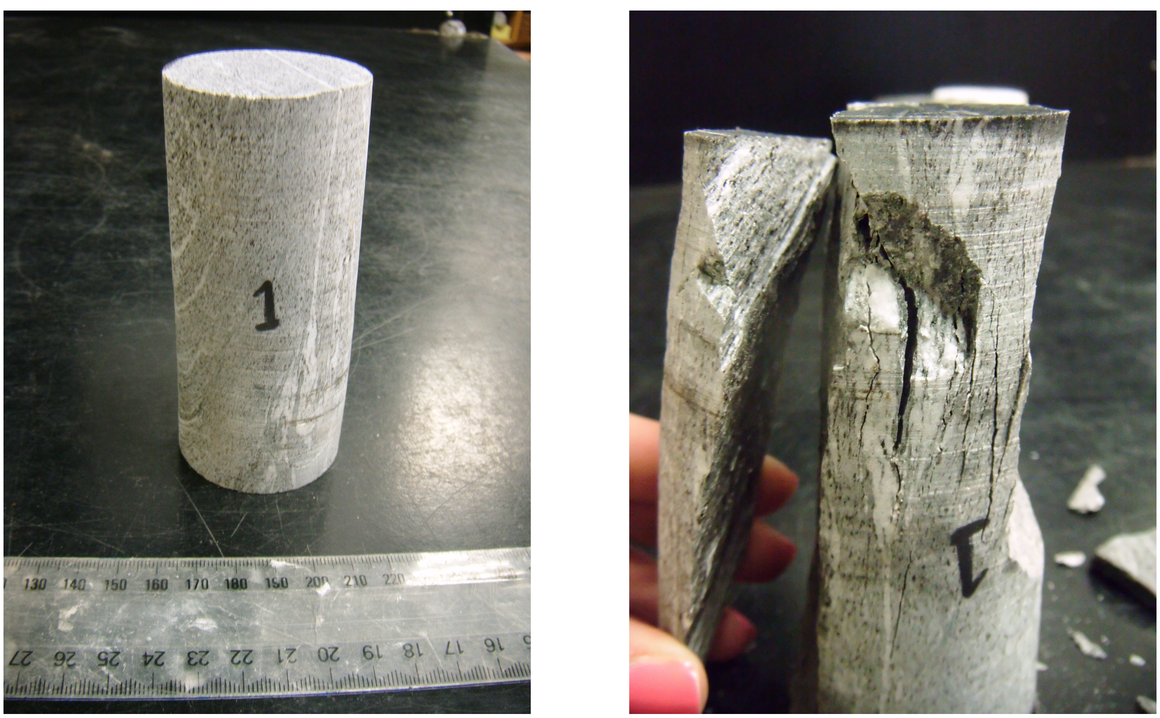


Figure 2-4: Sample 1 prior to UCS testing (left) and after testing (right).

Sample 1 failed at 48MPa, which is relatively low in comparison to the other tests. As seen in Figure 2-4 above, the sample broke along the schistosity, and had a dilative type failure through the top of the core where it seems to have been forced outwards along the foliation by the applied stress. Failure preferentially occurred along the boundaries with larger quartz bands, along which there were thin bands of micas aiding the failure. The sample did not break through intact rock, but has split down these weaker boundaries. No weathering or weathering products were present, suggesting that this was not a pre-existing defect.

2.3.4.2.2 Sample 2

Figure 2-5: Sample 2 prior to UCS testing (left) and after testing (right).

Sample 2 failed at 57.7MPa – a higher value than sample 1 in conjunction with the changed orientation of the schistosity relative to the loading direction. As seen in Figure 2-5, the failure surface was rough and through intact rock, showing that this is a representation of intact rock strength. One side of the core failed through intact rock on a diagonal, while the other side peeled off down the length of the core also through intact rock. Both failure surfaces showed fresh breaks through clean, unweathered rock.

2.3.4.2.3 Sample 3

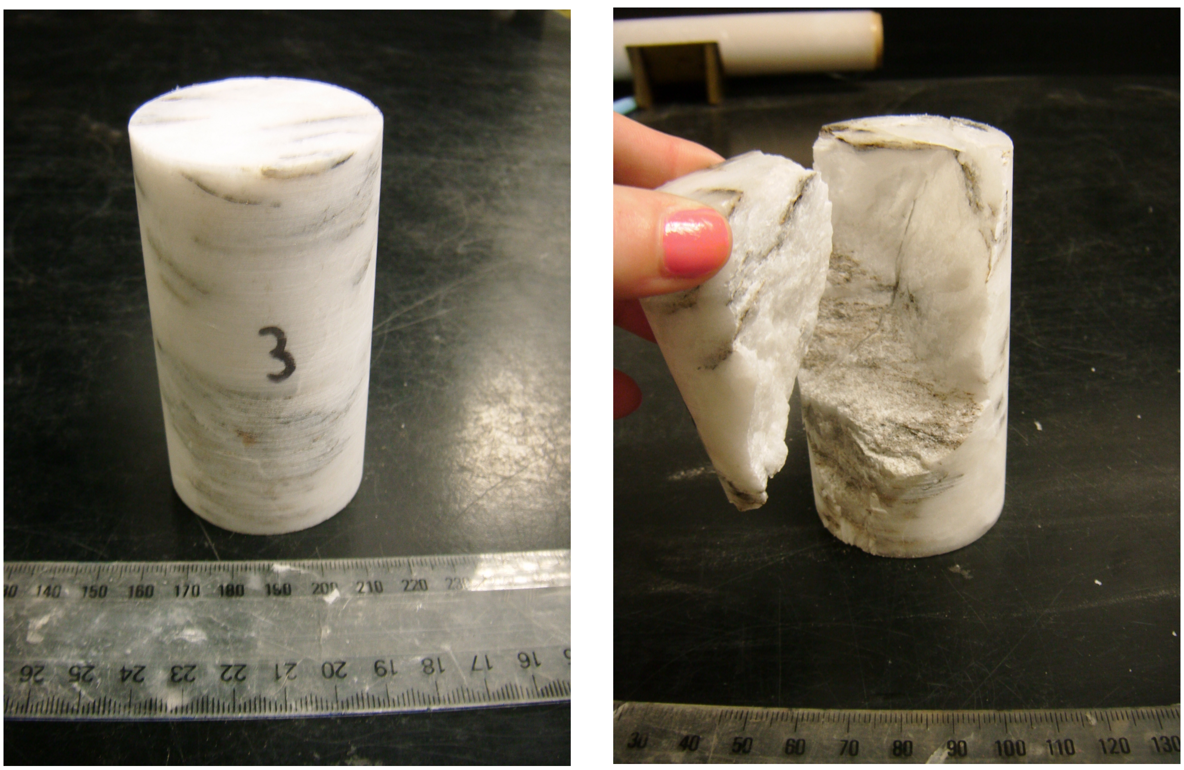


Figure 2-6: Sample 3 prior to UCS testing (left) and after testing (right).

Sample 3 failed at 40.4MPa, lower than all other samples, but the surface was rough and unweathered, similar to the other samples. As seen in Figure 2-6, sample 3 almost entirely comprised quartz, with a few darker bands of biotite throughout. Overall, it did not have foliation fabric as the other samples did. The core failed through intact rock in a diagonal sense and failure was only somewhat controlled by the biotite bands. These bands had an effect where the failure surface intersected the side of the core, causing the failure surface angle to shallow out and break along the bands rather than through intact rock. This could have had an effect on the strength of the rock and may have caused the lower strength.

2.3.4.2.4 Sample 4

Figure 2-7: Sample 4 prior to UCS testing (left) and after testing (right).

Sample 4 failed at 67.8MPa, the highest value of all the samples. As with sample 2, it was cored with foliation perpendicular to loading direction, which resulted in a high compressive strength. The failure surface propagated through intact rock and through the whole length of the core. It was rough and unweathered, showing this is again representative of intact rock strength.

2.3.4.3 Discussion

Ideally, it would be preferable to have undertaken more UCS tests. However, due to sample constraints only four cores were successfully cut, limiting results.

Failure surfaces were mainly rough, unweathered and through intact rock, apart from sample 1, which failed along a foliation. This means samples 2 and 4 can be used as an intact rock strength estimate (sample 3 is not used as it is not from a lithology typical of the rock mass). Sample 1 shows a minimal intact rock strength value, however it is probably not the absolute minimum value, as this would occur in the intact rock along shear zones and areas with weakened fill. Although sample 1 had mica on the failure surface, there was no evidence of fluid flow or clay formation, showing that the surface was not as weak as some other measured joints and shears. Sample 3 was slightly influenced by the biotite bands within the core, as is shown where the failure surface intersects the side of the core.

Orientation of the core relative to the foliation was shown to be a major influence on the compressive strength of the sample: where the sample had foliation parallel to stress direction the core was a lot weaker than when the foliation was perpendicular to stress.

The size of the cores were under the ISRM recommended diameter/length ratio of 1:2.5 (due to block spacing and sample size), ranging from 1:2.3 to 1:1.8 (ISRM, 2007). However in cases where it is this close, the smaller ratio has been shown to have a minimal impact on the strength outcome, so no correction was applied to these results (Tuncay & Hasancebi, 2009).

2.3.5 Point Load Testing

2.3.5.1 Methodology

The Point Load Test was developed originally due to its portability and versatility with sample sizes (Broch & Franklin, 1972). The point load test was used due to its ability to test smaller samples and the ability to use ‘irregular lumps’. The smaller samples collected from the tunnel walls were unable to be cored and UCS tested due to insufficient diameter/length ratios (ISRM, 2007). Point load testing allowed a rapid estimation of the rock strength and multiple tests on the one sample could be undertaken.

Details of the test calculations and photographs of specimens before and after testing are available in appendix C.3. This testing was undertaken in conjunction with ISRM guidelines (ISRM, 2007).

The point load strength index, I_s (MPa), is calculated as the ratio of the failure load to distance of platen separation at the time of failure. The effect of sample size on the strength value is calibrated to a standardised platen separation of 50mm, and presented as the $I_{s(50)}$ (Brook, 1985). Because the irregular lump method was used for the samples, a size correction was applied. I_S varies as a function of D_e in this test, so a correction is applied to obtain a correct strength value for samples (ISRM, 2007). Equivalent core diameter (D_e) is calculated as follows for irregular lump tests:

$$D_e^2 = 4A/\pi$$

This equation was then used to obtain the 'size correction factor *F:*

$$F=(D_e/50)^{0.45}$$

Size correction is then applied using the formula:

$$I_{s(50)}=F \text{ x } I_s$$

Point load testing was conducted on eight samples taken from specific points along the chainage of the tunnel to provide peak strengths of the intact rock mass for input into the engineering geological model. Due to the block size of these samples, the 'irregular lump' test was utitilised which negated the need to core the samples. Samples were also tested from the same rock that was UCS tested (see appendix C.2, sample 'M'), so that a multiplier to derive UCS could be calculated linking the two tests.

2.3.5.2 *Summary Results*

Table 2-3: Summary results of point load testing, showing averaged values for samples tested with foliation orientation both parallel and perpendicular to stress direction. Full results for the 16 tests can be found in appendix C.3. Sample locations can be seen in Figure 2-3.

FOLIATION RELATIVE TO STRESS	P (kN)	AREA (=W*D) (mm^2)	$I_{S(50)}$ (MPa)
Parallel	3.1	1035	1.95
Perpendicular	15.7	1483	7.82

Using the irregular lump test meant that a few tests could be conducted on each sample block, and could be tested with foliation both parallel and perpendicular to stress direction. Eight tests in each direction were completed.

Parallel testing gave $I_{s(50)}$ results ranging from 0.10-3.3MPa, with an average of 1.95MPa (averages were calculated by discarding the highest and lowest values). All failures broke along foliation, and failure surfaces were very flat and smooth with micas present (in some cases weathered micas and fine silt were present).

Perpendicular testing gave $I_{s(50)}$ results ranging from 1.82-10.10MPa, with an average of 6.24MPa. Failure surfaces in this case ranged considerably. Five of the eight tests were successful, and failure was through intact rock. Surfaces were rough, with no sign of weathering or any pre-existing defects along the surface. However, three of these tests were invalid (ISRM, 2007), due to the sample breaking along foliation, usually causing a piece to flake off the top or bottom of the sample without having a through-going failure surface (Figure 2-8). This limited the results available, but it is still clear that the samples in this direction had a higher overall strength than those oriented parallel to stress direction.

Figure 2-8: Test 2a from sample 2, showing the invalid result caused by failure along foliation. No through-going failure plane was achieved.

2.3.5.3 Discussion

Although this data set is larger than that of the UCS tests, it is recognized that a more in depth estimate of intact rock strength is desirable and could be achieved through further testing.

Failure surfaces varied between parallel and perpendicular samples. Parallel samples broke along schistosity and were therefore very smooth with traces of mica and clay in some cases. Perpendicular failure surfaces were rough where they cut through intact rock, and did not follow foliation (apart from the invalid cases). Examples of these valid tests are shown in Figure 2-9 and 2-10.

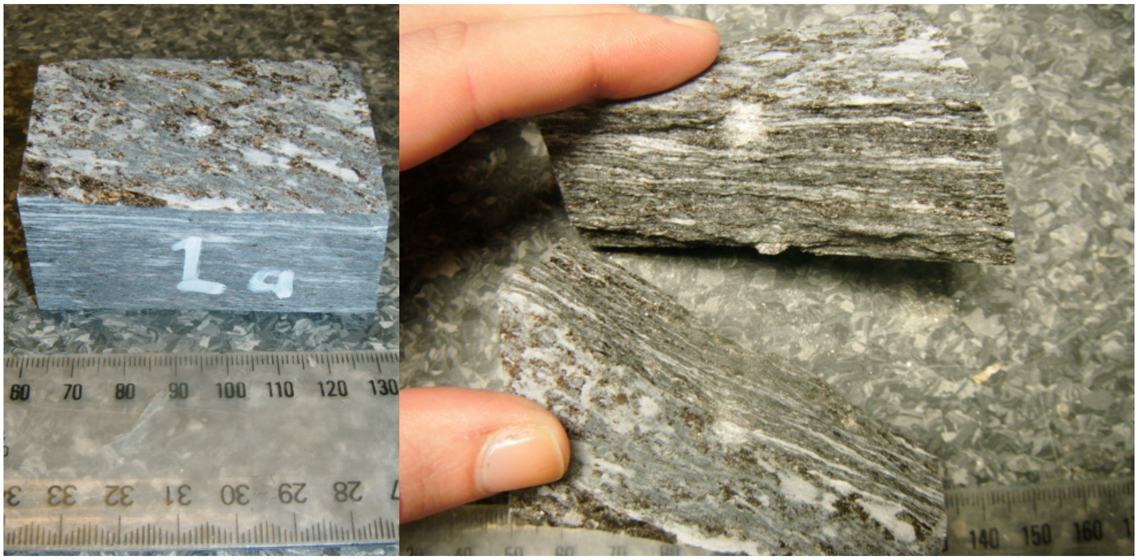


Figure 2-9: Valid perpendicular point load test showing failure through intact rock, with a freshly broken failure surface.

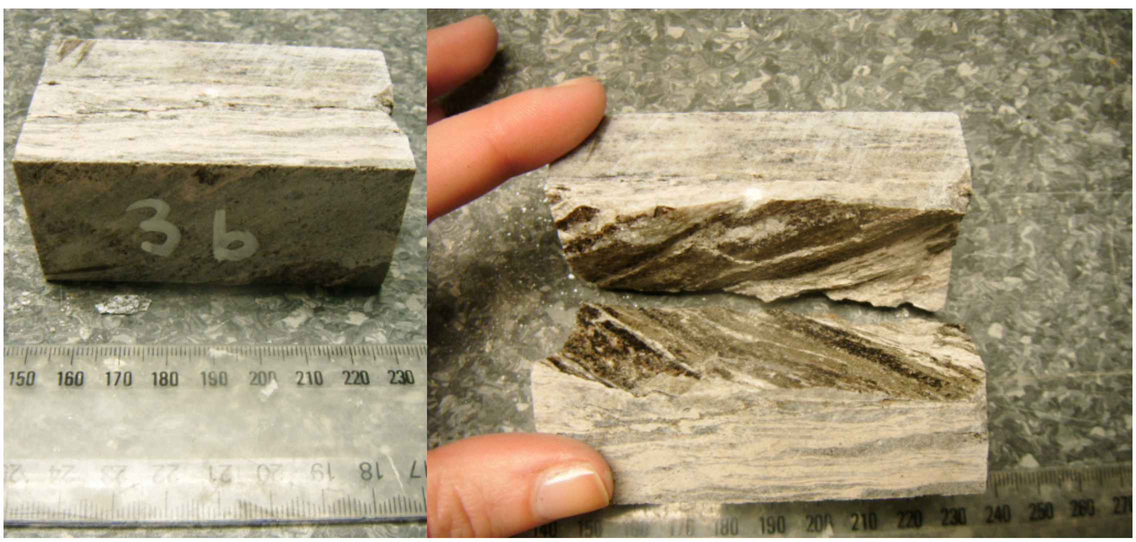


Figure 2-10: Valid parallel point load test showing failure through intact rock, along schistosity (not invalid in this case as the failure surface still propogates between the two points of the platens without deviating).

As with UCS testing, orientation of the samples was shown to have a large influence on the strength of the rock: foliation tested parallel to loading direction was much weaker than tests where foliation was perpendicular. However, these perpendicular tests were prone to failing through schistosity, causing the test to be ‘invalid’ according to test criteria. Because the tests were unconfined, the rock was allowed to break along schistosity, which may not have happened in an in-situ setting such as within a rockmass. This shows the strengths of these invalid tests may be underestimated.

2.4 Discussion and Synthesis

The principal aim of the engineering geological investigations undertaken for this thesis has been to provide representative geological input data for the development of an engineering geological model of the rock mass into which the Amethyst Hydro Tunnel was constructed. Both field investigations and laboratory investigations have taken place.

Field investigations provided data on rock mass properties such as: defect orientation, spacing and characteristics; rock mass quality; hydrological characteristics and changes with tunnel construction.

Laboratory testing involved seismic velocity, unconfined compressive strength and point load strength testing. Both UCS and PLT methods were used due to the sample size constraints and the lack of available samples able to be removed from the walls. Testing showed that foliation orientation is a significant control on the strength of the rock mass. Although maximum intact strengths were calculated when tests were undertaken with the foliation perpendicular to stress direction, the rock is unlikely to break like this in-situ, as was shown during the point load tests. Applied stress will break the rock along the path of least resistance, which could be along foliation, through a clay-filled shear or through a joint.

Sample bias has also affected the calculated intact rock strengths. The samples used for both point load testing and unconfined compressive strengths were collected due to their larger block size or their availability to easily be pulled from the walls. This means the samples have survived construction blasting so may be slightly stronger than average. They may however be subject to blast-induced micro cracking which may have decreased their strength. These two factors may negate each other if they are both true of every sample, but it is difficult to say whether either or both happened to every, or any sample.

Chapter 3
Engineering Geological Model

3.1 Introduction

After field investigations had taken place and all possible data had been collected and prepared, the engineering geological model of the rockmass into which the tunnel was constructed was developed. This model involved three main parts, which together encompassed all of the relevant characteristics for this rock mass. This gave an understanding of how the rock mass as a whole system was behaving and being affected by the construction of a tunnel within it. The sub-models are:

- Structural Model – including all discontinuity types, broken up into domains based on orientations and characteristics of these. The structural model formed the main basis for the engineering geological model as changes in orientation of defects were linked to shear zones and thought to be related to tectonic influences from the Alpine Fault and the Amethyst Ravine Fault. Large shear zones were seen to bound each structural domain and may be linked to changes in defect orientation.

- Hydrological Model – including hydrological features, broken up into domains based on extreme changes in background groundwater flow. This model is closely related to the structural model, as large inflows were related to the domain-bounding, clay-filled shear zones identified in the structural model.

- Rock Mass Model – including lithology types, wall strengths (intact and rock mass), and weathering profiles. The lithology types did not vary greatly, going from debris flow to weathered schist to fresh schist. The weathering profile within the schist likewise did not vary greatly.

The aim of these models is to develop a sound engineering geological model of the overall system being affected by tunnel construction. The model and its three main parts are useful for input into a 3D numerical model in order to identify areas of wall and roof stability. The model will also be useful for future tunneling projects in similar rock and geotechnical conditions.

3.2 Rock Mass Characteristics

3.2.1 Introduction

One of the most important parts of the engineering geological model is establishing the characteristics of the rockmass. The rock mass characteristics govern the stability of the excavation and its ability to stay open over the tunnel design life. In particular, factors such as lithology, rock strength, structure orientation, spacing and continuity, and groundwater flows can influence the way the rock will respond to construction and influence the amount of over-break or unraveling that will occur. The rock mass properties are intimately linked to the amount of support necessary, which in turn is linked to contractual specifications regarding the cost of construction and the amount of support deemed necessary at the feasibility stage.

The Amethyst tunnel has mainly been constructed in Haast Schist. The rock has varying alteration and weathering and in parts of the tunnel shows higher levels of metamorphism as exhibited by gneissic textures. The west portal of the tunnel has been excavated into debris flow material (up to 70m chainage). This is, however, under extensive shotcrete so no observations within the tunnel could be made. The main analysis was undertaken on the Haast schist material.

3.2.2 Debris Flow Deposit

Due to a last minute change of portal location, this unit was not identified in any of the pre-feasibility stage assessments. It could also not be classified during mapping within the tunnel due to being covered by shotcrete and pre-cast concrete sections at the portal. Because the debris flow material is non continuous within the tunnel, and extensively supported, no laboratory testing was undertaken on this material. It was difficult to say how far into the tunnel the debris flow material was present, but from the Shift Reports prepared during tunnel construction a simplified picture of the geology can be derived.

From the portal of the tunnel (0m chainage) to 17m, the drillers describe a ‘colluvium’ style material that is like soil with large clasts of rock within it, which matches observations made to the right of the portal, and has been taken to be the debris flow material.

3.2.3 Haast Schist

The Haast schist is a foliated metamorphic rock with very well defined foliation planes (defined by quartz and biotite bandings). These bands are typically 1-2mm thick but can be up to 10mm thick (with very large quartz bands (up to 200mm) in places).

A summary of the main rock characteristics follows:

- Geological Formation: Haast Schist Group
- Rock Type: Schist
- Rock Description: Grey, medium grained, well foliated with distinct mineral banding
- Composition: Quartz, biotite, feldspar and other accessary minerals such as garnet (based on visual inspection – no petrographic studies undertaken)
- Strength: Approximately 48MPa-68MPa (based on laboratory strength testing). This is moderately strong – strong according to the NZGS classification scheme (2005). Maximum strength approximately 68MPa, minimum strength variable, but depends on defects and defect fillings (such as clay within shear zones).
- Weathering Conditions: Slightly weathered to fresh (based on visual inspection of tunnel during construction), although a transitional zone of weathered soil/rock was identified from 17m to 70m

Engineering Geological Description: Unweathered - slightly weathered, grey, foliated, SCHIST. Moderately strong - strong, foliation dips 30-84^{o} (steepening up chainage) well developed; several sheared zones along foliation. Variable joints, very continuous.

Engineering Geological Parameters - derived using generalized Hoek-Brown criterion analysis for intact rock in RocData (Rocscience, 2004) (full input parameters in Appendix F):

- Internal angle of friction: ~48^{o}
- Cohesion: 3.33 MPa

Bulk modulus (21.3) and shear modulus (18.4) values for the intact rock were obtained through Hoek-Brown analysis in RocData (Rocscience, 2004).

Friction angle and cohesion for the intact rock were obtained through Hoek-Brown analysis in the RocData program, as with bulk and shear modulus, and cohesion and friction angle for the defects were determined in RocData using the Barton-Bandis criterion (Hoek, 2007c).

Figure 3-1: Picture typical of the Alpine schist seen within the tunnel. Mineral banding (quartz, feldspar and biotite) is of both varying thickness and continuity throughout the tunnel. White scale bar is 300mm

From 17m to 70m the drillers describe a reddish-brown rock, varying in strength and hardness. At times, it can be milled and at other times must be blasted. This has been interpreted as a transition between the debris flow and weathered schist underneath it. It is difficult to say exactly where the unweathered schist starts, but by 70m chainage, the drillers classify the material as 'rock', which is too hard to mill at all, and must be blasted. In addition, the geological log starts at 78.5m chainage and by this point the lithology is Alpine Schist (Smith, 2011).

3.2.4 Discussion

Because the tunnel is only constructed in one major lithology, it is imperative that the characteristics of this lithology are well defined in order to develop a reliable and representative engineering geological model of the rock mass. The core log seen in appendix B.3 shows that variations in weathering do occur within the tunnel, but overall the rock is only slightly weathered – un-weathered. This means weathering has little to no effect on the overall strength of the rock. One area in the tunnel (approximately 500m chainage) showed increased precipitation of a bright orangey-red ooze on the walls of the tunnel. This did not seem to be related to increased weathering in the rock itself, and did not seem to be associated with the rock, but precipitating out from the water flowing along the joints. It is thought that this is related to the warm springs often seen directly to the east of the Alpine Fault (section 1.4.2), which also appear adjacent to this location in the Wanganui River. No chemical analysis was attempted on this precipitate, but it did not appear to be having an effect on the underlying rock or weakening it in any way (observed by scraping the precipitate off and using a rock hammer to test it's strength).

The schist is relatively homogeneous in that there is little variation throughout it. However, there are areas of higher-grade metamorphism, where gneissic banding can be found. Because no petrology was undertaken on the rock, this hasn't been officially mapped as gneiss, although the foliation spacing increases in places and gneissic foliation texture is visible. These areas seemed to incur less blast damage in the tunnel and appeared to form more intact walls, indicating that this rock could have a higher intact strength than the schist. It exhibited less defects, and schistosity in these areas was rare to non-existent, showing that these areas would be more competent. For this reason, although this higher metamorphosed rock hasn't been analysed or laboratory tested, designing the tunnel to the relatively weaker schist would be a conservative approach as the presence of any gneiss would not compromise the stability of the tunnel. The areas of gneiss mapped were all localized and were from 844m chainage to at least 950m (where scanline mapping ended and full shotcrete to the floor started).

3.3 Rock Discontinuities

3.3.1 Introduction

The discontinuities in the rock have the foremost impact on the overall stability of the rockmass (Priest, 1993). The defects within the schist included foliation (most pervasive and continuous of the defect types); shear zones (varying thicknesses and infill types – primarily acting as conduits for water flow) and joints (highly variable, continuous throughout the tunnel with varying spacing and lengths).

The defects have been extensively analysed and classified in order to create a realistic and representative structural model, which has been used to create a numerical 3D model of the tunnel. The characteristics of the rock discontinuities are the main influence on the behaviour of the rock after tunnel construction, and have an impact on the overall stability of the rock and its interaction with any support used during construction.

3.3.2 Schistosity

3.3.2.1 Thickness of Mineral Banding

The thickness of the quartz/feldspar bands varies from 0.1mm to 20mm thick. There is no pattern with the change in thickness (i.e. no thickening or thinning up or down chainage) and it can be highly variable on metre scales.

3.3.2.2 Infill

There were multiple types of infill within the foliation. The majority of open foliations were clean, with no filling present.

The next most common type of infill was reddish brown clay, which could have been derived from micas, weathered over time (see core logs, appendix B.3). There were also instances of bluish-grey clay which was similar to that found within the shear zones (see section 3.3.3.2).

The least common type of infill encountered could be classified as light brown silt to fine sand, which was only observed twice through the whole length of the tunnel.

3.3.2.3 Orientation

The orientation of the schistosity fits into a very distinct group on a stereo plot as seen in Figure 3-2. The schistosity steepens up the tunnel chainage, and the dip direction changes. The dip direction of the schist at the intake end of the tunnel is aligned closer to the tunnel alignment of 156°, whereas closer to the portal end the foliation dips further towards the east (135°).

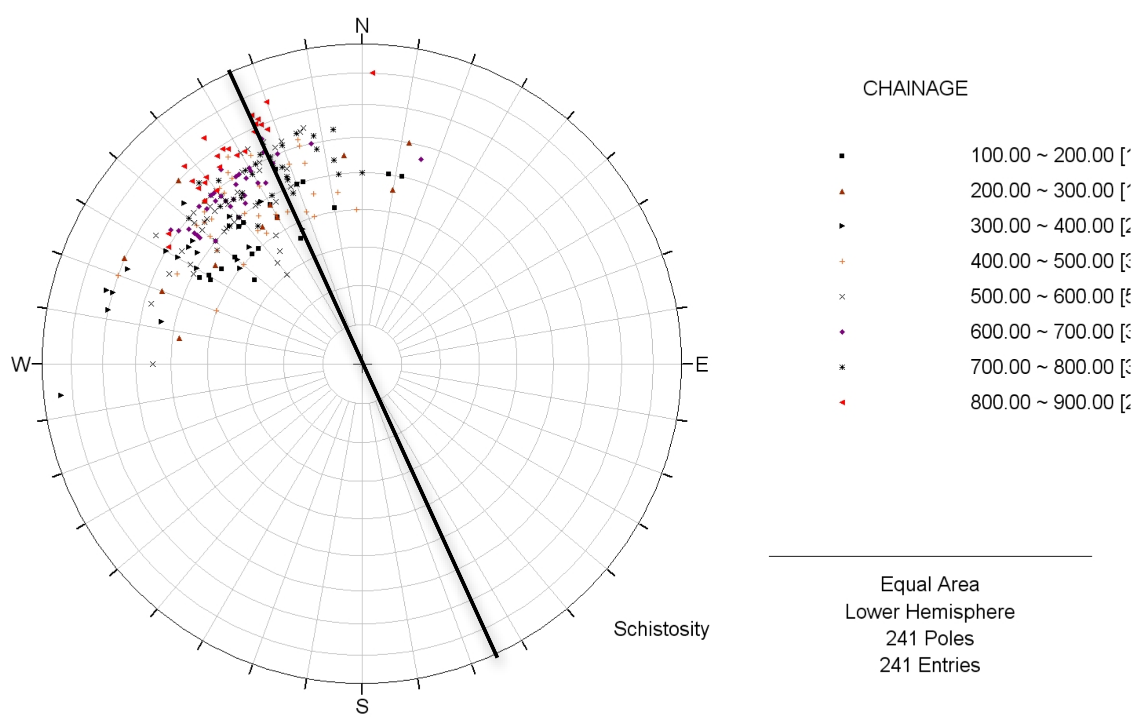


Figure 3-2: Equal area stereo plot of schistosity in the tunnel showing the distinct group of orientations. Tunnel alignment is shown by the black line (156°).

3.3.3 Shear Zones

Prominent shears and shear zones were found at varying intervals along the tunnel and appeared to have a greater effect on overall rockmass stability than the other defect types, through increased water flow, poor tunnel profile in these zones and a weakening of the overall rock mass. These shears had varying aperture, infill and orientation, but all seemed to be influencing the flow of groundwater. Unfortunately, limited information is available on some of the shears due to the timing of fieldwork and the need to shotcrete over the shears soon after exposure for greater stability. Nine could be logged during fieldwork and detailed information on their aperture, infill, orientation and other attributes can be found in the scanline mapping data in appendix B.2.

3.3.3.1 Aperture

These shears were classified as anything exceeding 10mm in aperture, although they varied in thickness from <50mm up to 200mm (rare). One shear zone recorded in the core and in production data at 440m chainage was 1.4m thick (Smith, 2011). Often the aperture was difficult to measure due to the infill within the shears creating gradational boundaries from crushed rock to un-sheared wall rock.

3.3.3.2 Infill

Infill was typically bluish-grey altered clayey-gouge material, although there were also instances of angular, quartz-biotite crush being present in the joints. Most commonly, the shear zones exhibited a ‘halo’ effect where the degree of shearing and alteration decreased further out into the walls from the shear zone. Alteration in most cases was in the form of oxidation/weathering. Clay/gouge graded out into angular crushed material, then into broken wall rock and into unaltered wall rock.

Although an exact compressive strength of this material was not measured, it was found that the clay gouge was extremely weak due to the ease with which it could be scraped, indented and squeezed into a ball (NZGS, 2005). This is supported by studies done on the San Andreas Fault, where it was found that clay gouge within a few kilometers of the fault was of a low enough strength to influence faulting rupture (Wu, 1975).

3.3.3.3 Hydrology

A major feature of the shear zones was their ability to transmit water. These shears in places were ‘clean’ where the water had flushed any filling away. Often during drilling into one of these zones, it was immediately obvious that a shear zone was ahead of the face due to increase in water volume coming out of the drill holes. The presence of fine grained/clayey gouge can promote the adsorption of water, although its fine-grained nature means gouge forms an impermeable barrier impeding the movement of water (Wahlstrom, 1973). This could be due to compartmentalized water across the impermeable clay gouge, which is released when breached during drilling. This was also found in the San Andreas system, showing this to be not uncommon near large fault zones (Wu, 1975).

This also has an effect on the rockmass as it can cause a lowering in cohesion across the shear, where the built up water pressure is ‘jacking’ the shear open. When the shear is drilled into and the pressure released, it may leave an open cavity, which creates a major weakness within the rock mass.

3.3.3.4 Orientation

Shear zones were variable in orientation, and only a few could be measured. By the time fieldwork was underway, most large shears through the tunnel had already been extensively shotcreted, due to the impact of the shears on overall tunnel stability. Some shears at chainage greater than 700m could be measured, as these were exposed while mapping was taking place. It was found that the majority of the shears followed the orientation of schistosity. Depending on whether shearing occurred pre or post metamorphism, shearing could have occurred through these pre-existing planes of weakness as they were already present in the rock, or could have evolved while metamorphism was occurring and schistosity was forming. Shearing was also present along joint set one and two orientations, but was not as prevalent.

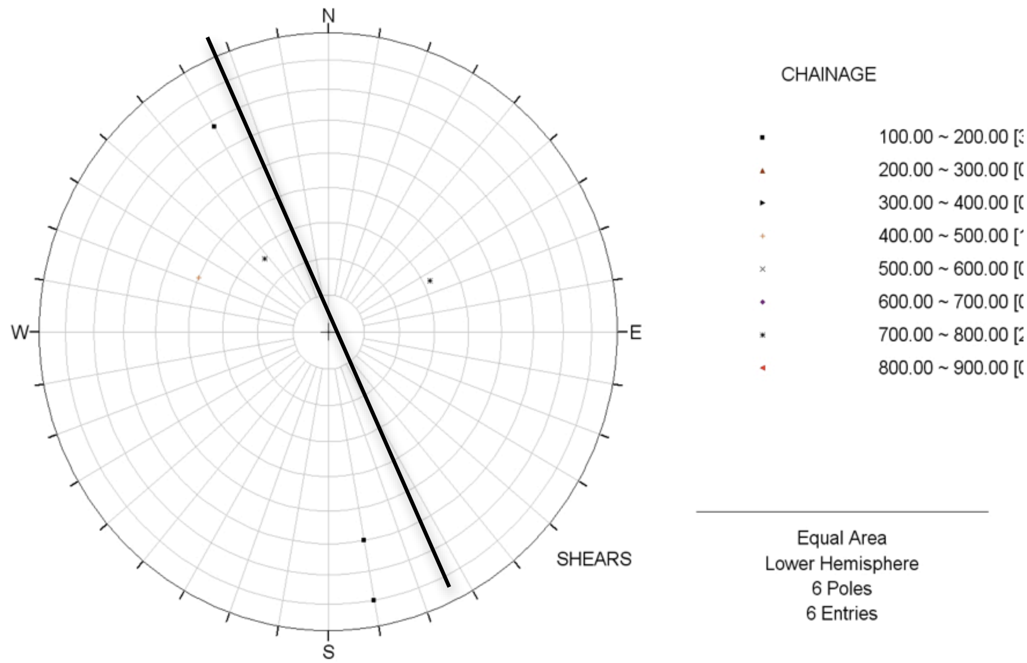


Figure 3-3: Equal area stereo plot showing the position of the nine logged shears. The majority of the shears (6) followed schistosity orientation, two followed joint set one orientation, and one shear followed joint set two orientation. Tunnel alignment is shown in black (Rocscience, 2004).

3.3.4 Joints

There were two main sets of joints present in the tunnel; joint set one and joint set two. These were extremely prevalent, and along with the schistosity, aided in creating a blocky rockmass. Joint set one formed a neat group with only slightly varying orientations; however joint set two comprised joints of extremely varying orientation (Figure 3-4). These joints had variable apertures, fill types and other characteristics (roughness, planarity etc.), which did not seem to follow any pattern. The joints had a large impact on the rock mass classifications undertaken (Q (Barton, Lien, & Lunde, 1974) and RMR_{89} (Bieniawski, 1989)), and the variability of joints on 3-5m scale resulted in the variety of rock mass classification values achieved.

3.3.4.1 Aperture

As with the schistosity and shears, the aperture of the joints was variable. Apertures between 0mm and 5mm were observed. There was no pattern with the aperture measurements, they seemed to be randomly distributed throughout the tunnel, and not influenced by chainage (distance from Alpine Fault), increased water pressures or any other factor.

3.3.4.2 Infill

An array of infill types similar to those visible within the schistosity was found to fill the open joints. As with the schistosity fills, it was difficult to see the infill of the joints in places due to shotcrete being applied to the exposed joint surfaces. It was easier to calculate the orientation and aperture of the joint, but the original rock surface was hard to discern.

The most common open joint observed had no filling – the surface was completely clean. These also often had water flowing through them. Another reason for these being so common could be the effect of blast damage causing these joints that were originally not open to open up and consequently they have no fill on their surfaces.

The next most common type of fill was brownish-red clay, as seen on the schistosity (section 3.3.2.2). 13% of joints showed this type of fill and as noted above, this may have been derived from weathered micas such as biotite which were abundant in the rock mass.

Finally, one joint had a silt-fine sand type fill, although this was only observed once and did not seem to be characteristic of the rock mass.

3.3.4.3 Orientation

The joints had the most variable orientation of all defect types found in the Amethyst tunnel. They were grouped into two main sets; joint set one and joint set two.

3.3.4.3.1 Joint set 1

This set formed a clearer cluster of orientations than joint set two. Joint set one was oriented roughly perpendicular to the schistosity set orientation in 3D space (taking into account the dip and dip direction (Figure 3-4).

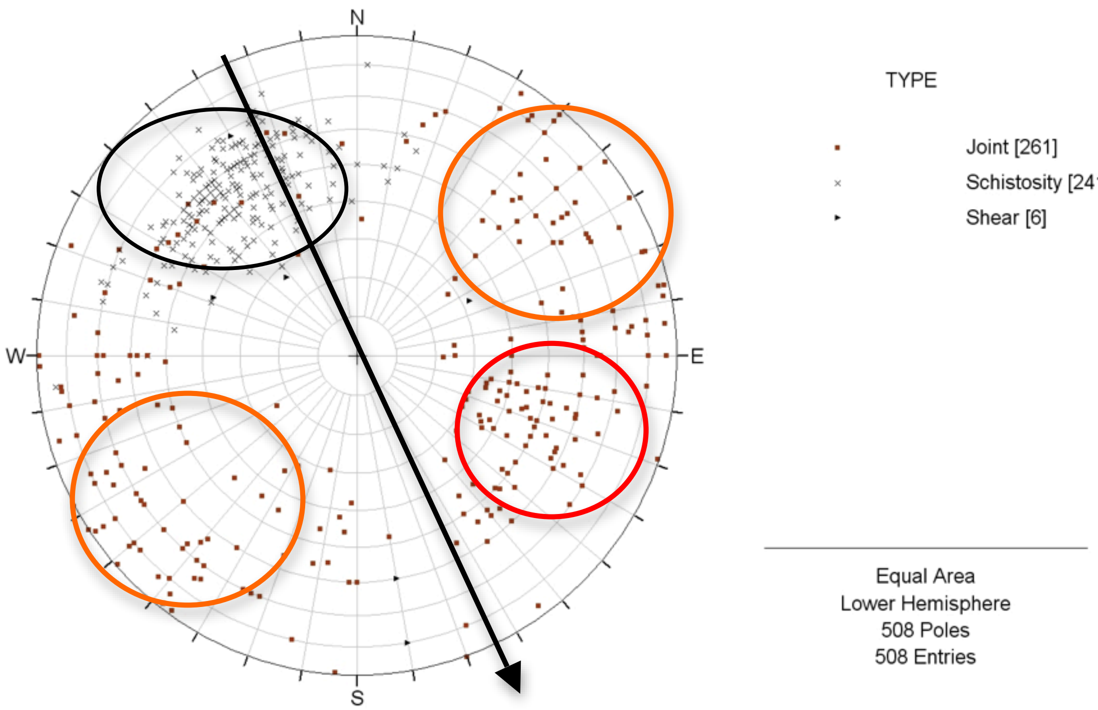


Figure 3-4: Stereo plot of the full data set, showing schistosity (black ring), joint set 1 (red ring), joint set 2 (orange rings) and tunnel alignment (black arrow).

3.3.5 Faults

Although faults were found/expected in the pre-construction reports ((Aurecon New Zealand Limited, 2009) & (Geotech Consulting Limited., 2006)), no faulting was observed within the tunnel during fieldwork. This is largely to do with the fact that in areas of decreased rock mass quality, there was increased support, which covered the rock and made observations impossible. There are large sections of the tunnel that were difficult to map in detail and therefore a fault in the tunnel could quite possibly exist.

Also, it is difficult to say whether some of the larger shears were faults or not, as these were mapped by the site geologist (Smith, 2011). Of the large shear at 440m, Smith (2011) stated:

Sheared zone in face has thickness of >1m, most likely the same sheared zone as the one picked up in the core (BH3) at ~288m. Sheared zone retains visually a lot of original foliation fabric but on closer inspection with a rod, it is very soft. A hand sample of the material showed how shattered the gouge was. Light grey and white colouring with some lenses of dark-light grey clay. The actual sheared zone feels damp but has no running water coming out of it. The sheared zone is along approx. orientation with foliation.

This statement shows that it was a large zone of decreased rock quality, but it is difficult to say whether there has been any displacement on it. The log for BH3 also recognized the presence of slickensides, showing there is a possibility some movement could have occurred.

The Tarpot Fault has been projected into the tunnel by designers as shown in BH4. The fault zone is projected to go from outside the tunnel portal, to 120m chainage (approximately). If this zone was present in the rock, it was not observed due to the full shotcrete covering the rock to 123m. It could possibly have led to the transition/weathered material (see section 3.4.3.3) between hard schist and debris flow deposit to be a lot weaker than would be expected, however this is uncertain.

Two major faults which may have an effect on the rock but which are not present in the tunnel are the Alpine Fault (approximately 5km south west of the portal) and the Amethyst river fault (forming the Amethyst Ravine at the intake end of the tunnel). Although these are not defects within the rockmass in question, they have an impact on the stress field the rockmass is under, and impact the structures present in the rock.

3.3.6 Discussion

Of the rock discontinuities present in the tunnel, the most important of these is the schistosity. This permeates the entire rock mass and is therefore the most widespread impact on the stability of the rock. The next most important are the shear zones, because while they are not as prevalent as the schistosity planes, the shears have a larger aperture, a weaker infill and form an important control on the presence of groundwater within the tunnel. Overall, they have a large impact on the rock mass where they are present. The least important defect type is the jointing. Although joints are continuous and create a blocky rockmass, they are variable and have a much lower average aperture than the shears. They are also less continuous than the schistosity. Defects ranged in roughness, but most were slightly rough, to rough. Some schistosity planes were smooth to slightly rough, but joints tended to be rougher than schistosity. Surface roughness has a large impact on the shear strength of the defect surfaces, and so any increases or decreases are very important in terms of the stability of the excavation (Hoek, 2007b).

Unfortunately, due to the amount of support used wherever the ground conditions deteriorated, measurements were often approximate or unable to be obtained in these zones, meaning the data acquired may only be representative of the better parts of the rockmass. Exact orientations on some shears were unable to be obtained also due to covering by support. Blast damage also created some bias when measuring joint and schistosity aperture. When the rock mass was intact it is difficult to know whether the open apertures observed would still have been present, or whether these were simply a by-product of blasting and excavation.

The amount of water present in the tunnel was also difficult to quantify in places, and it was difficult to analyze the origin of the flow. A joint that had flowing water in the roof could lead water to flow down the walls, making it difficult to see whether the joints in the walls were also discharging water or whether it was all from above.

Overall, the rockmass is structurally complex, and the defects present have been characterized based primarily on their orientations. As can be seen in Figure 3-4, the schistosity and joints fit nicely into clusters of orientations showing there is some pattern to their formation. These defect characteristics can be used for input into the engineering geological model in order to predict what effect on stability they will have.

3.4 Domain Analysis for input into the Engineering Geological Model

3.4.1 Introduction

Domaining of the rockmass was undertaken in order to break the tunnel up into areas of similar characteristics for input into the final engineering geology model of the tunnel. Three models were created for this: a structural model, a hydrological model and a rockmass model, each taking into account various aspects of the total dataset collected.

It was important to have these three different aspects of the engineering geological model broken up separately, due to their differing impact on the rock and the different rock mass behaviour types they characterized.

3.4.2 Methodology

The rock mass parameters were firstly broken up into separate areas based on what aspects of their individual parts were particularly important to the overall long-term stability of the tunnel. These factors were decided by looking at the rock mass classifications Q and RMR_{89} that had been calculated during mapping, and seeing which parameters had the largest impact on the final classification of the rock in any given area. Due to the inherent differences between the two schemes, they were compared and contrasted in order to assess what parameters were most important and having the most impact in the individual domains of each model. The largest disparities (both within the individual classifications and between the two schemes) were investigated to see what parameters were having the most impact on the final value. For this reason, the structural model was created first (being the most important), followed by the hydrological model and finally the rockmass model.

3.4.3 Domain Identification

3.4.3.1 Structural Model

The structural model was very important in this rock mass due to the number of types of defects and the variety of defect characteristics present. This was broken up primarily based on what defect types were having the largest impact to the stability of the overall rockmass, as identified in the analysis of Q and RMR mapping results (see above). Using the stereonets created, changes in defect orientations were used to break up the tunnel into primary domains. The tunnel was broken up into five domains within the structural model: one domain for shears and four domains representing changes in the orientation of schistosity along the tunnel. As can be seen in Figure 3-5, the shears form the major boundaries between domains 2, 3, 4 and 5. These domains show a marked change in dip and dip direction (note the stereonets in Figure 3-5) of the schistosity, and this seems to be linked in some way to the shears. The joints did not change down the tunnel following any set pattern, so there could be no correlation made between changes in aperture, infill, spacing or frequency up the chainage.

3.4.3.1.1 Alpine Fault Influence

The changes in orientation of schistosity with increasing chainage may be linked to the rock mass being situated between the Alpine Fault to the West and the Amethyst Ravine Fault to the East. It is possible that the faults are rotating the block of rock between them, and this is causing orientation changes. The shears may also be taking up some of this strain, which leads to incremental steepening of dip direction closer to the Amethyst Ravine Fault.

3.4.3.1.2 Domain 1

It was found that shears (defects with clay or gouge infill greater than 10mm thick) were the most influential to rockmass stability due to their thick, low strength filling and high water pressure in places. These were therefore classified in a domain of their own. This domain included areas where schistosity and jointing was also present but shears were having the largest impact on rock stability.

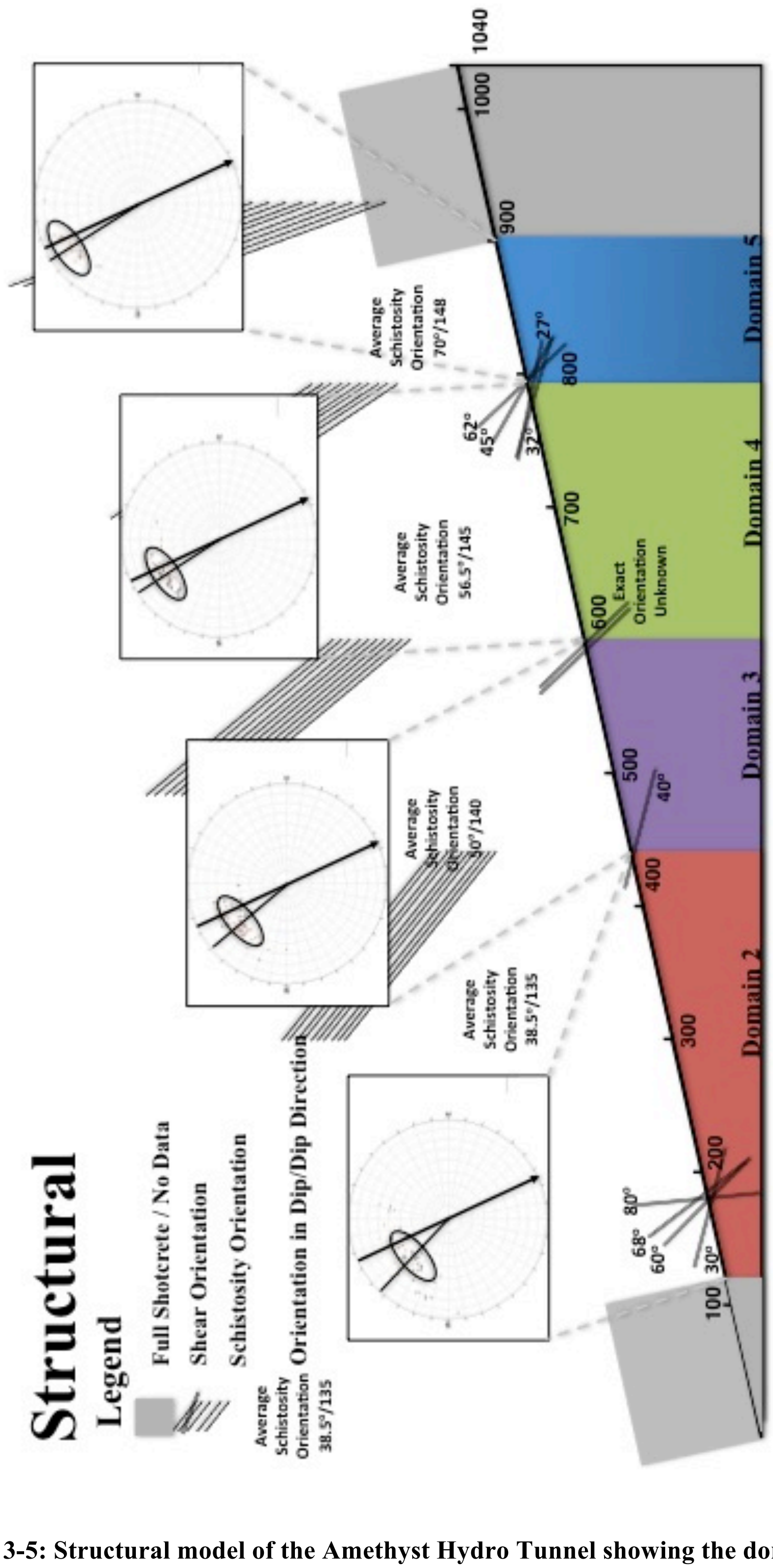


Figure 3-5: Structural model of the Amethyst Hydro Tunnel showing the domains 2-5 with stereoplots showing change in dip and dip direction of foliation.

3.4.3.1.3 Domain 2

The next domain was based on changes in schistosity (the next most influential defect type). Out of domains two to five, domain two had the shallowest dipping schistosity, dipping closest to the east. The average for this domain was a dip of 45^o and a dip direction of 133^o.

3.4.3.1.4 Domain 3

This domain was also based on a change in schistosity orientation occurring after a large shear. Domain 3 schistosity had an average dip angle of 50^o and a dip direction of 140^o.

3.4.3.1.5 Domain 4

As with domains two and three, domain four was based on schistosity orientation and showed a steepening in dip and a change in dip direction to become closer to parallel with the tunnel alignment. Average schistosity dip angle was 55^o and dip direction was 147^o.

3.4.3.1.6 Domain 5

Domain 5 showed a final steepening in the dip of foliation, and dip directions coming very close to parallel with tunnel alignment. Average dip was 65^o and dip direction was 148^o.

3.4.3.2 Hydrological Model

The hydrological model is very important in determining the water pressures acting on the rock mass and also in determining the strength reduction factor (SRF) due to water pressure that will occur on the joints and defects (Hoek, 2001).

This model was grouped simply into areas of water inflow and areas where the tunnel was dry. This was achieved by plotting total water outflow from the face of the tunnel (Smith, 2011) against chainage of the face at the time of measurement. This resulted in a cumulative plot of water outflows (unfortunately there was no equipment in place to measure instantaneous outflow from the face at any one point in time/chainage). This model was defined in conjunction with the structural model as they were found to have very close links.

As can be seen in Figure 3-6, water inflows are controlled by major shear zones. Comparing Figure 3-6 to Figure 3-5 shows that every major shear zone encountered has an associated increase in water volumes entering the tunnel. This further confirms the importance of understanding the behaviour of the shear zones from a rock mass stability point of view (except at 790m where no water data was collected although shift reports and mapping show there was an inflow of water around this area).

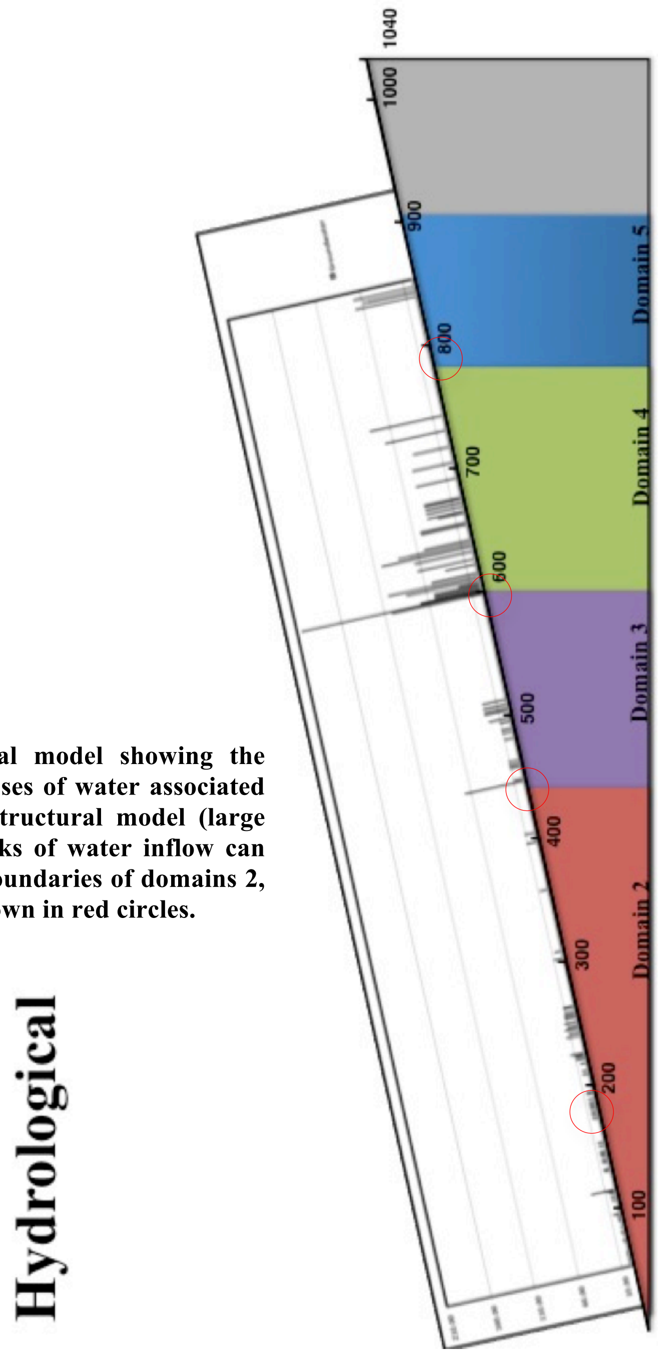


Figure 3-6: Hydrological model showing the incidence of large ingresses of water associated with domain 1 of the structural model (large shear zones). Large peaks of water inflow can be seen at the domain boundaries of domains 2, 3, 4, and 5. Domain 1 shown in red circles.

3.4.3.3 Rock Mass Model

The rock mass model incorporates all the other characteristics of the rock mass that are not covered by the hydrological model or the structural model. These include lithology, weathering, defect conditions and intact strength changes in the case of the Amethyst tunnel. Rock strength data from UCS tests and PLT results were most important, along with incorporating any changes in defect conditions (roughness, aperture, spacing), as these aspects had the most importance on overall rock mass stability. Weathering and lithology were not significant variables in the creation of this model as they showed minimal variation along the tunnel.

3.4.3.3.1 Lithology

The lithology does not have any significant changes along the length of the tunnel. However, the tunnel does cut through debris flow deposit at the portal end for an unknown length (estimated to be from 0m to 17m chainage). This deposit was not well classified due to a last minute change in tunnel alignment and the extensive support applied to the area due to the lower strength nature of the deposit (see section 3.2.2). After this, the tunnel cuts through a weathered transitional section before transecting primarily Alpine Schist, although periodic instances of higher metamorphic alteration resulting in gneissic textures are also present.

3.4.3.3.2 Weathering

Weathering along the tunnel varies slightly but does not seem to have an overall impact on the quality of the rockmass. As can be seen in Figure 3-7, the weathering (recorded during rock mass classification in conjunction with scanline mapping) is relatively variable but overall the majority of the tunnel is fresh to slightly weathered. The rock is at sufficient depth that surface weathering processes seem to have had little effect, while fluid movement through defects has produced localized pockets of increased weathering and appears to be the dominant cause of weathering in the rock mass.

3.4.3.3.3 Defect Conditions

Defect conditions varied throughout the tunnel and had the most impact on the overall quality of the rockmass. As shown in section 3.3, defect conditions were highly variable within the three main types: shears, schistosity and joints. Because the defects acted as the weakest planes throughout the rockmass along which failure was most likely to occur, these conditions, in conjunction with the structural model, were a vital parameter to add in to the rock mass model and the overall engineering geological model.

Defect conditions such as aperture width, infill type and length showed no specific changes along the length of the tunnel, nor did they follow any patterns. As shown in the structural model, defect orientation showed a clear change and therefore this is the characteristic that has been most focused on, as having the largest impact on variability in the rock mass.

3.4.3.3.4 Intact Strength Changes

Intact strength was measured through the point load and UCS tests undertaken as described in sections 2.3.4 and 2.3.5. As also discussed in these sections, due to the lack of samples able to be collected and therefore the relatively few tests undertaken, the intact strength for was projected for the entire tunnel based on these samples. There was a maximum and a minimum intact strength recorded, based on the direction of the test relative to the foliation direction. The maximum intact strength found would occur if any stresses within the rock mass induced failure through intact blocks, but this is not realistic, as failure would preferentially occur along the path of least resistance: a joint or shear surface, or through slippage on foliation. This means that although the rocks tested exhibited these higher intact strengths, in the observed environment, the rock mass strengths would be a lot lower.

Changes with increasing chainage in the tunnel were difficult to ascertain, but core logs and strength tests showed that the more highly metamorphosed areas of gneissic schist had higher strengths and were harder to break than the regular and more common biotite schist. Within this biotite schist however, strengths did not change significantly.

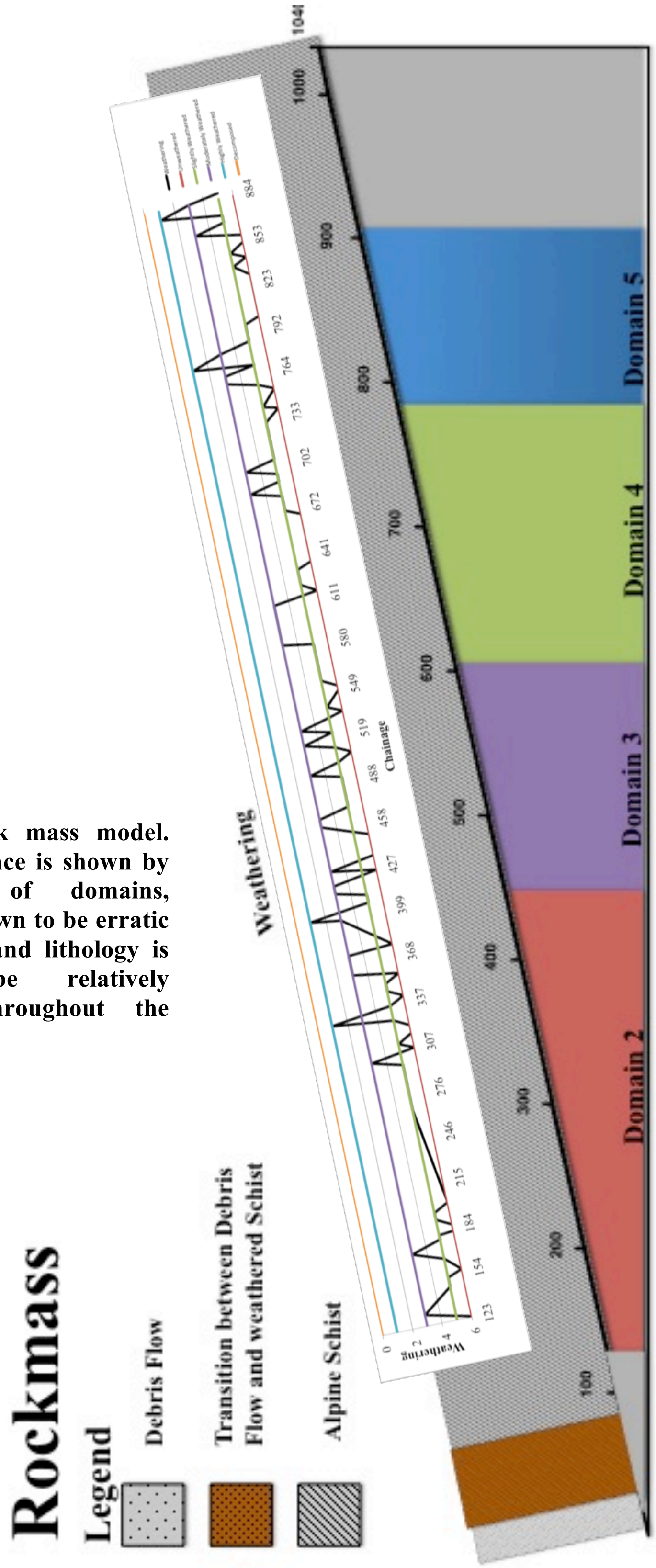


Figure 3-7: Rock mass model. Structural influence is shown by the presence of domains, weathering is shown to be erratic along chainage, and lithology is shown to be relatively homogeneous throughout the tunnel.

3.5 *Rock Mass Classifications*

3.5.1 *Introduction*

Rock mass classifications are often used in the design period of a major civil or mining project involving engineering geology. They provide a scoring system whereby the rock mass is given numbers based on how 'good' or 'bad' it is perceived to be (Hoek, 2007a). Depending on the purpose of classification, the rock mass, and the final end use of the project, different classification schemes may be used and all have varying pros and cons.

During the design phase of the Amethyst Hydro Project, the rock mass (as described in the exploratory boreholes) was classified using the Q system (Barton et al., 1974). The total classification scheme for this can be found in Appendix D.2. Because of this, during fieldwork and mapping of the tunnel it was decided to take Q values every 5m, but to also supplement these values using the RMR_{89} scheme and see how the two systems linked together. Both systems apply different weightings to the variable parameters within the rock mass. Therefore it has been investigated how much of an impact the differences had on the overall classification of one section of rock.

3.5.2 *Application of Q and RMR_{89}*

3.5.2.1 *Barton's Q System*

The Q system (see appendix D.2) is an empirical method which determines rock mass characteristics and tunnel support requirements (Hoek, 2007a). Q ranges from 0.001 for exceptionally poor rock to 1000 for exceptionally good rock and uses 6 parameters to rate the rock mass (Barton et al., 1974). The six parameters include:

- RQD - Rock Quality Designation
- J_n – Joint set number
- J_r – Joint roughness number
- J_a – Joint alteration number

- J_w – Joint water reduction factor
- SRF – Stress reduction factor

These are combined in the equation:

$$\mathbf{Q=(RQD/Jn).(Jr/Ja).(Jw/SRF)}$$

These parameters together represent the rock block size, inter-block shear strength and active stress of the rock mass, and using the weakest joints in the classification (smoothest joints, weakest filling, most alteration, most water etc.) a conservative estimate of rock mass quality can be found (Barton et al., 1974).

Q was used in the Amethyst Hydro project to determine the support classes used in differing areas depending on their calculated Q values (see appendix D.2). Q values were taken by the site geologist whenever possible in order to determine which support class to use. Support involved combinations of different thicknesses of shotcrete, rock bolts and in very poor rock, pre tensioned cable bolts into the invert.

Q does not take into consideration the joint orientation in relation to the tunnel alignment and is a generalised scheme in relation to its applicability to many different scenarios. This means more than one system should be used during the design phase to be able to compare rock mass ratings.

3.5.2.2 RMR_{89}

The RMR was originally proposed in 1976 by Bieniawski, but has since been revised extensively to change the ratings assigned to different parameters (Hoek, 2007a). The RMR_{89} is most appropriately applied to a rock mass divided into a number of structural domains, separated by major structural features such as faults or changes in rock characteristics (Bieniawski, 1989). The six parameters used to classify a rock mass using RMR_{89} are:

- UCS - Uniaxial compressive strength of rock material
- RQD – Rock Quality Designation
- Discontinuity spacing
- Discontinuity condition
- Groundwater condition
- Discontinuity orientation

The first five parameters are all rated and summed together to give a total classification value out of 100 (see Figure 3-8 for parameter weightings). This value is then adjusted for the sixth parameter - discontinuity orientation - to give a final score for the rock mass (see full scheme in appendix D.1).

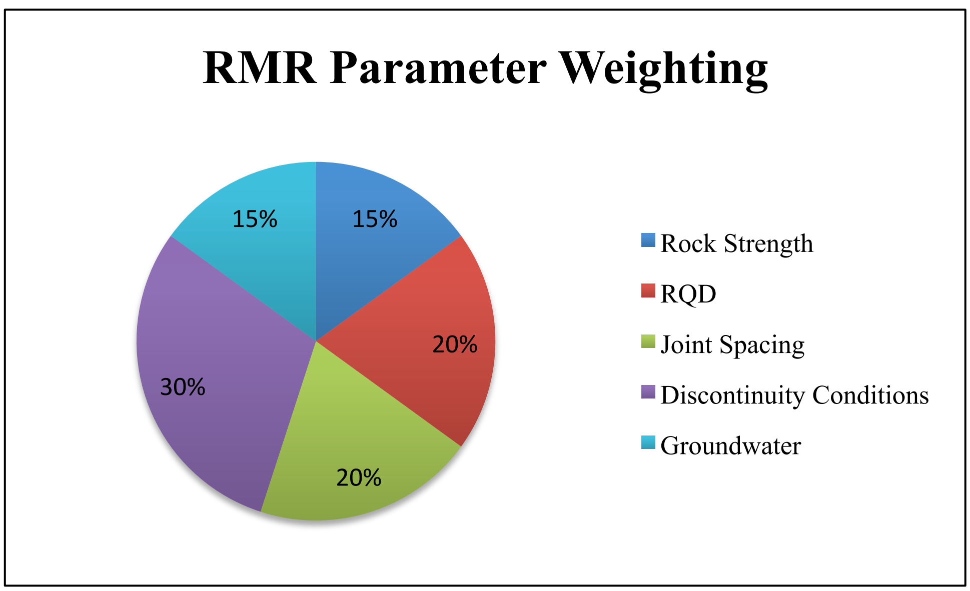


Figure 3-8: Pie chart showing the relative weighting of different parameters rated within the RMR_{89} system. The final value is then altered for joint orientation.

RMR_{89} was not used during the design of the Amethyst Hydro Project; only the Q value of the rock was taken into account. During fieldwork, it was decided to use this value to compare to the measured Q values in order to see the changes between the two rating systems within the same rockmass.

RMR differs from Q in that it does not take into account the number of different joint sets, but it does take into account the overall joint spacing of the area and also the orientation of the excavation/wall being measured with regards to the joint orientations. This reinforces the point that in an ideal situation, more than one classification system should be used during the design stage of the project, and during construction, to determine most accurately the quality of the rock being rated.

3.5.3 Discussion

The two rock mass classification systems have been developed separately, in different rock masses and for different purposes. These have been originally developed to suit a case situation in a specific area. Therefore, they weight the importance of varying parameters differently and will not be a perfect fit to a rockmass different from what the systems were designed to rate. For this reason it is important to always use multiple rock mass classification systems in order to come up with a closest fit. In the case of the Amethyst tunnel, this has shown that analyzing the rock mass from borehole data alone and by using only one classification system does not accurately portray the full nature of the rock. This led to unexpected ground conditions being encountered during construction, which in turn led to delays in construction. In addition, because both the rock mass and the Amethyst Hydro Project differ from the area and purpose for which these systems were originally developed, certain parameters are more or less important to this area and particular project. This highlights the need to understand the systems that are being used for design and importantly, their limitations.

Although the two systems did produce similar results over approximately half of the tunnel chainage (see Appendix D for results), there was also a significant disparity between the two (see Figure 3-9). RMR_{89} values were higher than Q values along 36% of the tunnel chainage, resulting in either an overestimation of rock mass strength by the RMR_{89} system or an underestimation of rock mass strength by the Q system. The opposite happens for 14% of the tunnel, where Q values are higher than RMR_{89} values. Although these two systems varied, no single one was more or less 'correct' than the other, as they both considered different factors. However, from observations made during mapping, it appeared the RMR_{89} fitted the rock mass more closely (that is, took into consideration parameters important to the stability of the rockmass, as opposed to Q which had a number of factors which were less useful for the rockmass), as the effect of changes in defect orientation were accounted for. The RMR_{89} also took into consideration joint spacing, and the block size of the rock mass was one of the key factors influencing over break observed during mapping. It is clear that the use of a single system in the design stage is insufficient, and preferably, design should take place from first principles to allow the classifications to be completely appropriate to the rock mass in question.

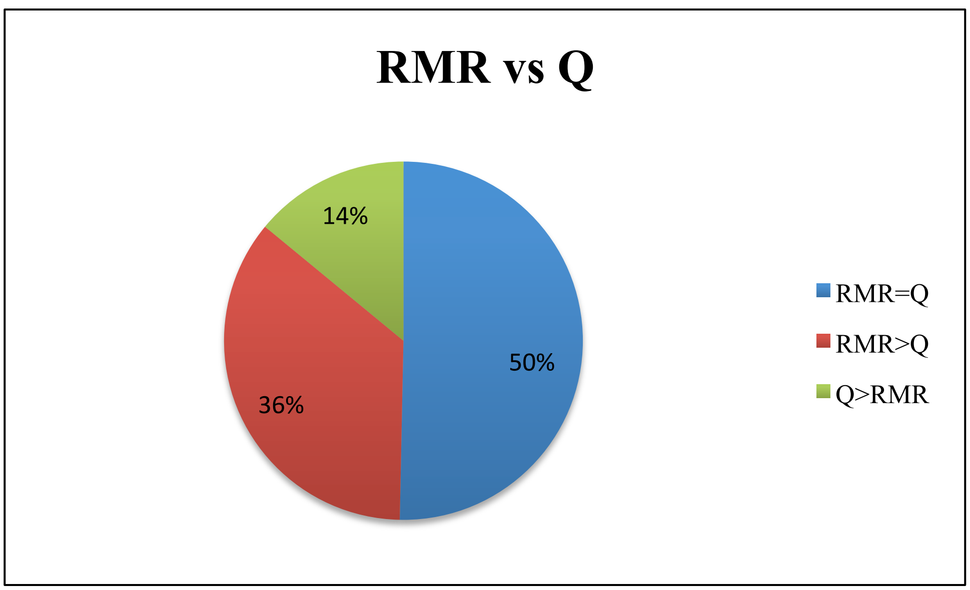


Figure 3-9: Pie chart showing how the RMR_{89} ratings compared to Q values obtained from the same areas within the tunnel. 50% of the tunnel chainage, the two systems came out with the same rating for the rockmass. 36% of the chainage, the Q value was lower than the RMR value, and 14% of the chainage the RMR value was lower than the Q value.

There are a few reasons these disparities between systems have happened, and they are all related to the systems themselves and the different weightings of various parameters.

RMR_{89} takes the orientation and spacing of discontinuities into consideration. This was important for the Amethyst Hydro Project, as the joints were very closely spaced (0.15-1.1m), and the orientation of the tunnel relative to the schistosity was an important factor influencing over-break and the geometry of the walls after blasting. Therefore, in places, the rockmass received a lower score in the RMR_{89} system due to deductions from orientation and discontinuity spacing, whereas these could not be considered when using the Q calculation for the equivalent area. Lower values of RMR_{89} tended to match up with areas of greater over break, as these areas often had closer joint spacing and smaller block size.

The Q system is a combination of three quotients - rock structure (RQD and Jn), shear strength (Jr and Ja), and active stress (Jw and SRF) (Maidl, Schmid, Ritz, & Herrenknecht, 2008). Therefore, any significant variations in Jn, Ja or SRF with regards to RQD, Jr and Jw respectively can significantly change the value of the final Q rating.

In the Amethyst Hydro project, the joint water and the joint alteration (filling) parameters were shown to have the most impact and were the most variable. These two factors led to large changes in rock classifications within small areas. Rock was measured as very poor in one area and fair only 5m away, simply due to an increase in joint alteration and flowing water. The rock mass did not necessarily always seem to correspond to these drastic changes in calculated quality.

The Q system is designed to use the worst-case scenario rock mass and defects, so the measurement in places may be over conservative. When the Q value alone is determining the support class to use (as was the case for the Amethyst Project), decreased rock mass classification leads to increased use of support and therefore higher costs for the project. It is in these places (36% of the tunnel chainage) that the RMR_{89} suggests that the Q value is probably underestimating the strength of the rock mass and a lighter support class could have been used with increased areas in discrete zones around major defects.

3.6 Discussion and Synthesis

Through looking at the rock characteristics and discontinuities, and rock mass classifications taken throughout the tunnel during mapping, domaining was undertaken for the rockmass, breaking it up into domains of similar characteristics and ultimately creating a comprehensive engineering geological model of the Amethyst Hydro Project.

Rock mass characteristics identified a tunnel mainly built in one lithology (Alpine Schist), but with a minor influence from mass movement processes (debris flow deposit), underlining the need to acknowledge the dynamic geomorphologic environment of the project area in the engineering geological model of the tunnel. Understanding the history of the area (see Chapter 1) is important to understanding the deformation history of the underlying rock mass. Tectonic processes also had an influence with significant faults and shears creating a geotechnically complex element of the engineering geological model.

The engineering geological model was broken up into three main parts, to accurately resemble the main influences to the rock mass in the project area. The structural model was most important from an engineering geological perspective, as it represents the stability and overall geomechanics of the rock mass and shows how the geometry of individual blocks (potential failure mechanisms) changes throughout the tunnel. Next most important was the hydrological model, as changes in this caused weakened areas within the rock mass as shears are jacked open by increased water pressures. The rock mass model was still an important part of the engineering geological model overall, but in this case was less significant as there were fewer variations in it throughout the project area.

Rock mass classification during mapping also allowed a preliminary view of what parameters were affecting the quality of the rock and how the different classification schemes varied in their ratings of the rock mass. The Q and RMR_{89} schemes were developed for specific uses and areas, and therefore applying these to the Amethyst Hydro Project was always going to have limitations to their effectiveness. However, the application of both systems simultaneously would have given a fair indicator of the rock mass properties, and a reasonably accurate idea of the support types needed. It has been shown that Q has an intrinsic tendency to underestimate the quality of a rock mass compared with RMR_{89} (as shown in Figure 3-9). Scanline mapping and classification of the tunnel using both methods demonstrated that these systems achieve parallel results 50% of the time, meaning 50% of the time, due to differing weightings of parameters within the two systems, the classification systems are not in sync. This reinforces the idea that at least two if not three classification schemes should be used during the design of any engineering geological project, in order to achieve a fair and accurate representation of the rock mass quality. It is important not only to use more than one scheme, but to understand how these schemes incorporate and weight the various characteristics of the rock mass. It is important to understand how this is related to the anticipated stability of the rock mass and the anticipated behaviour. For example, within this rock mass, RMR_{89} has been shown to be an appropriate scheme for use where the schistosity is dominating the behaviour and for domaining of the rock mass. Q was shown to have valuable qualities as well, and was appropriate for classification of the sheared zones within domain 1. Understanding which classification system works best for which characteristics would allow the two systems to be used effectively in tandem, leading to the most closely accurate estimation of rock mass quality.

Chapter 4
3DEC Modelling

4.1 Introduction

With the engineering geological model established, the data were prepared for 3D numerical modelling. Modelling was aimed at providing an idea of how the rockmass would most likely behave and deform once the tunnel was excavated, in order to compare this expected behaviour with what was observed in the tunnel and the support design used. The debris flow material and Domain 1 are not discussed in this chapter, as these are not part of the hard rock model and will behave in a different manner. These have been discussed as part of the engineering geological model as a whole. Domain 1 was a set of shears that occurred at varying places up the tunnel. These shears would have a large impact on the surrounding rockmass, but these models aim to isolate key contributors to the rock mass behaviour (such as the discontinuities) without the compounding factors of other observed characteristics such as water. The debris flow deposit material is not used in the 3D numerical model, as it does not have an impact on the large-scale rock mass behaviour. The model was primarily to look at the likely kinematic behaviour of the rock mass, and the debris flow material would not deform in this way

A synthetic rock mass was built using 3DEC – a three-dimensional numerical program based on the distinct element method for discontinuum modelling (Itasca Consulting Group Inc., 2010). This allowed for a simulation of characteristic joints, foliations and other such features to be prepared before the tunnel was excavated through it and deformations were observed. Modelling allowed a comparison between the observed kinematic behaviour and the prescribed support classes in order to examine how well they worked together. The data were first analysed using JointStats – a program designed for the statistical analysis of measured joint sets and their associated properties ("JointStats," 2000). The following chapter explains the parameters used during modelling and the outcomes generated by 3DEC and interprets the results of the modelling.

Domains 2, 3, 4, and 5 were statistically analysed in JointStats, in order to make sure outcomes could be generated. The data were checked to make sure that a sufficient number of joints in each set were ‘uncensored’ (both ends of the joint visible in the tunnel wall), in order to get an accurate approximation of persistence. These domains were then modeled in 3DEC.

4.2 JointStats Analysis

4.2.1 Introduction

Statistical analysis for input into the final distinct element model was completed using the JointStats program ("JointStats," 2000). This was done for the purpose of providing confidence limits for the values, in order to input the mean and standard deviation values for the defects into the final 3DEC model. The structural domains (and their associated discontinuity data) derived from the engineering geological model were entered into JointStats as scanlines on a 2D plane (representing the wall of the tunnel). JointStats used the discontinuity data from each domain to obtain mean and standard deviation for dip, dip direction, spacing and persistence. Persistence is the areal extent or size of a discontinuity, and can be quantified by observing the trace lengths of discontinuities on exposed surfaces. Structural analysis of the rockmass as described in section 3.3.4 found two main joint sets in the rock mass, along with the foliation. These two sets were then analysed using Monte Carlo simulations to find their persistence values. As the foliation was considered fully persistent (p=1), no JointStats analysis was undertaken on this. Schistosity did however change in dip and dip direction in each domain, and so the values for average dip and dip direction for input into the 3DEC domain models were obtained through analysis of stereonets (Figure 3-2) and averaging of dip and dip direction values obtained from scanline mapping (Appendix B.2.).

4.2.1.1 Joint Sets 1 & 2

An average spacing was obtained through JointStats analysis of the scanline data. As shown in Figures 4-1 and 4-2, set spacing information was calculated by JointStats, showing that Joint Set 1 had an average spacing of 3.2m and Joint Set 2 had an average spacing of 2.7m. Persistence and standard deviation were also required for input into the

3DEC model. The analysis of the joint sets found that Joint Set 1 had a persistence of 0.24 and Joint Set 2 had a persistence of 0.21.

4.2.2 Validation Issues

It was found that JointStats was unable to process the data successfully when entered on an inclined scanline, as existed in-situ from the incline of the tunnel. For this reason, the data was projected down onto a horizontal plane, and the chainage measurements were corrected (Appendix B.2.).

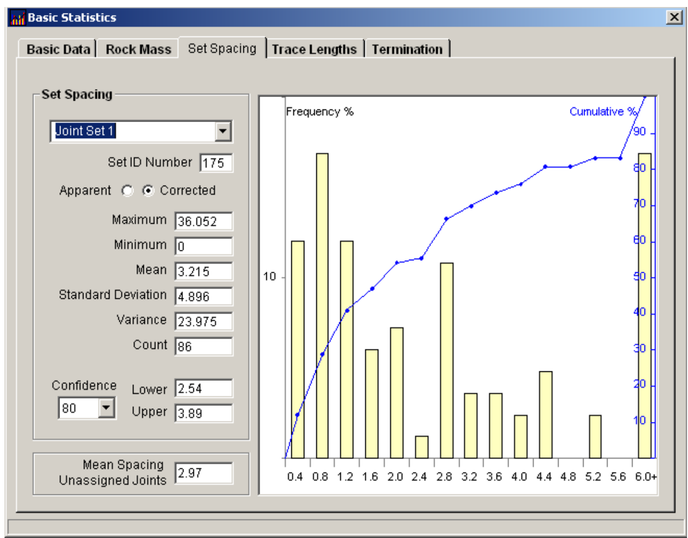


Figure 4-1: Screenshot from JointStats showing the set spacing statistics of Joint Set 1.

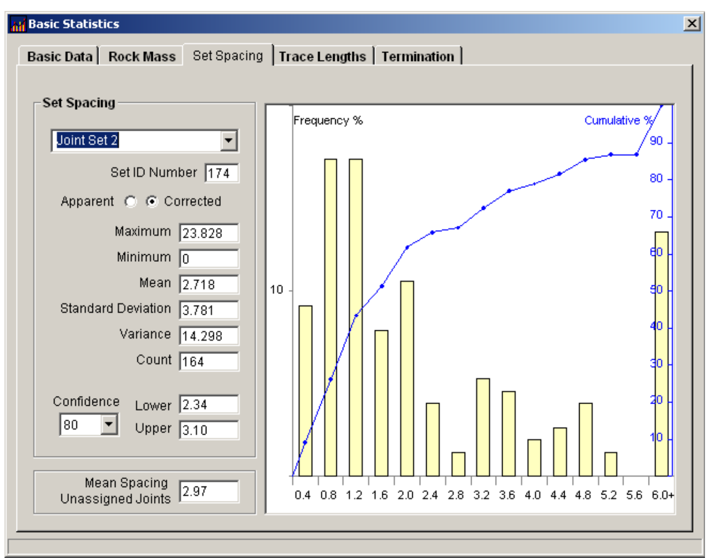


Figure 4-2: Screenshot from JointStats showing the set spacing statistics of Joint Set 2.

4.3 3DEC Modeling

4.3.1 Introduction

Once statistical analysis had been completed, 3DEC (Itasca Consulting Group Inc., 2010) was used to create a representative rockmass for Domains 2-5 from the engineering model, using the parameters obtained from JointStats analysis and from the scanline data of actual rockmass attributes measured. The structural model was most important for this, as the structural changes within the rock mass were the main factors in determining the domains.

4.3.2 Model Geometry

Each domain was modeled separately as a basic square block with an inclined tunnel cut through it. The origin of the x y z grid/coordinates was in the centre of the tunnel (X and Y directions) at the invert (Figure 4-3).

Figure 4-4 shows the dimensions of the block used. A representative length of 20m (Y direction) was used for each domain. This allowed a thickness of over 5 times the width of the tunnel, and allowed for joint spacing of approximately 1m (the average spacing of Joint Set 2) to be simulated on average 20 times. This meant different failure modes could be captured, but did not make the block so large as to adversely affect run times of the individual domain models. The model was 26m across in the X direction in order to encompass the 3.5m-width tunnel plus 3 times the width again on each side of the tunnel. This allowed any boundaries to be far enough away from the tunnel so as not to affect the stability of the tunnel walls and artificially strengthen or weaken the tunnel. Likewise in the Z direction, the model was 34m in order to encompass the 3.5m height of the tunnel, the 4.43m rise of the tunnel over its 20m length (due to the incline) and 3 times the height of the tunnel again both above and below both faces. This again allows the boundaries to be distant enough to have no effect on the tunnel during stressing.

After the block was established, the tunnel geometry was cut through but not excavated. This did not have an impact on the deformation or stability of the model, as the joints forming the tunnel outlines had no properties or influence on the model until the tunnel was

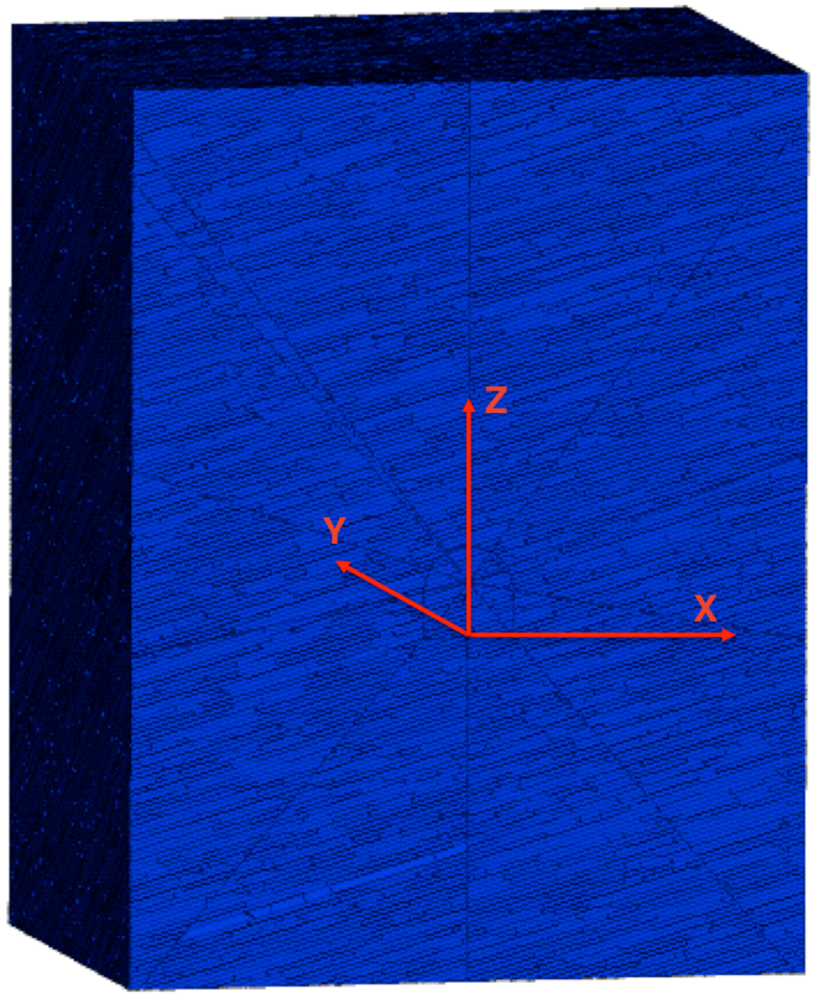


Figure 4-3: Screenshot of the model after the tunnel has been cut and defects added. Tunnel can be seen in the centre of the X face, and the coordinate system used is shown.

excavated. The tunnel was cut but not excavated prior to initialization, as it was found that the initialization stage had an effect on the coordinate system of the block, meaning the tunnel would not excavate properly.

After the tunnel had been formed within the model, the schistosity and joints were added. As the tunnel was cut straight through the model (but in reality it is on an orientation of 156^{o}), it was necessary to change the orientation of the schistosity and joint sets in order to have them on the correct orientation relative to the tunnel.

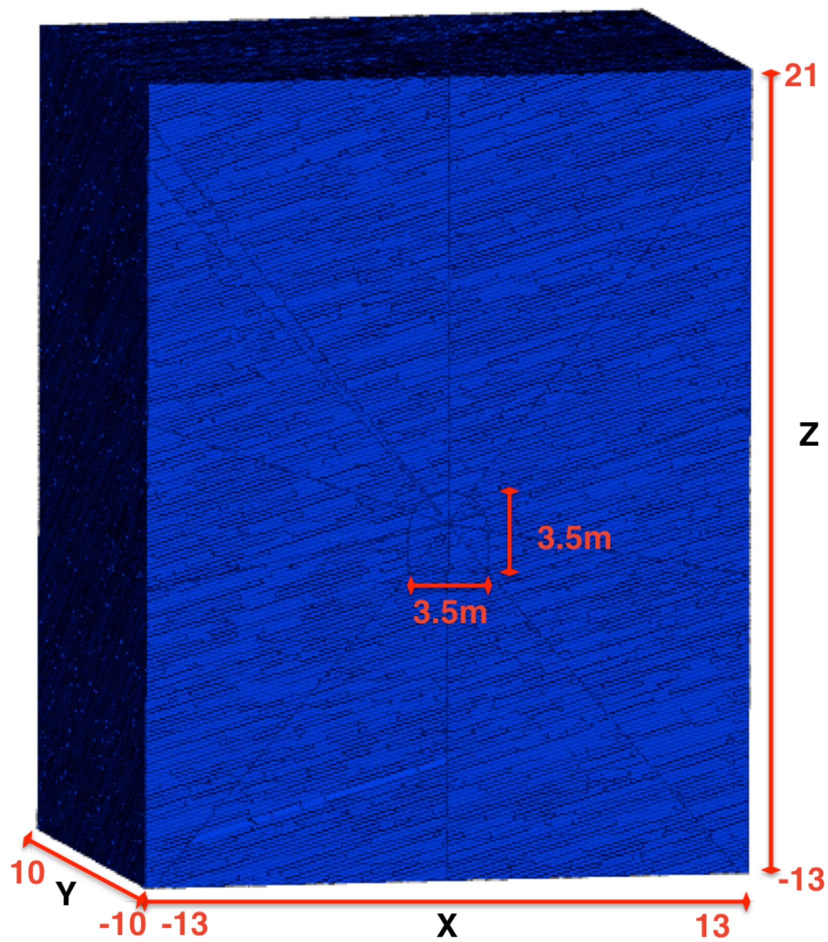


Figure 4-4: Model showing X Y Z dimensions, and dimensions of the tunnel in the centre.

4.3.2.1 Input Parameters

Due to the close and regular spacing of the defects, it was found that the model had a large number of blocks, which affected both the amount of memory used by 3DEC during processing, and the run time. The large number of blocks also meant that deformable blocks with Mohr-Coulomb properties could not be used as the model had difficulty calculating the boundary conditions for the numerous small blocks present. For this reason rigid blocks were used, although some parameters for Mohr-Coulomb calculations were still calculated. Table 1 shows a summary of the main input parameters used. A complete version of these can be found in Appendix F.1.

Table 4-1: Summary of the main input parameters used for the four 3DEC domain models (full table in Appendix F.3).

	Domain 2			Domain 3			Domain 4			Domain 5		
	Schistosity	Joint Set 1	Joint Set 2	Schistosity	Joint Set 1	Joint Set 2	Schistosity	Joint Set 1	Joint Set 2	Schistosity	Joint Set 1	Joint Set 2
Jointset ID	1	2	9	1	2	9	1	2	9	1	2	9
Ave Dip	38.5	53.9	69	50	53.9	69	56.5	53.9	69	70	53.9	69
Ave D Direction	135	312.5	225.3	140	312.5	225.3	145	312.5	225.3	148	312.5	225.3
Ave D Direction Model corrected	339	156.5	69.3	344	156.5	69.3	349	156.5	69.3	352	156.5	69.3
Origin	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0
Spacing	0.15	0.8	1.1	0.15	0.8	1.1	0.15	0.8	1.1	0.15	0.8	1.1
Persistence	1	0.24	0.21	1	0.24	0.21	1	0.24	0.21	1	0.24	0.21
Number	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Shear stiffness (Ks)	202	202	202	202	202	202	202	202	202	202	202	202
Normal stiffness (Kn)	132	132	132	132	132	132	132	132	132	132	132	132
Friction angle (defects)	33.75	33.75	33.75	33.75	33.75	33.75	33.75	33.75	33.75	33.75	33.75	33.75
Cohesion (defects) MPa	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110

Table 4-2: Summary table of intact rock properties used for the four 3DEC domain models. (Only density used due to rigid block model being used).

	Schistosity	Joint Set 1	Joint Set 2
Jointset ID	1	2	9
Density kg/m^3	2660	2660	2660

The origin of each joint set was arbitrarily placed at the origin of the coordinate system. Likewise, Joint Number was an arbitrarily chosen number, large enough that the entire block would be cut with the joints depending on the spacing of the individual sets.

Contact normal (kn) and shear stiffness (ks) for each joint set were set extremely high (1GPa) during initialisation in order to knit the blocks together and prevent any premature movement. Later, after excavation of the tunnel, these were changed to be weaker – from

1GPa each to 132 and 202 MPa respectively. These values were taken from another study undertaken by Varo and colleagues using UDEC to model granitic rocks (2011).

4.3.3 Boundary Conditions

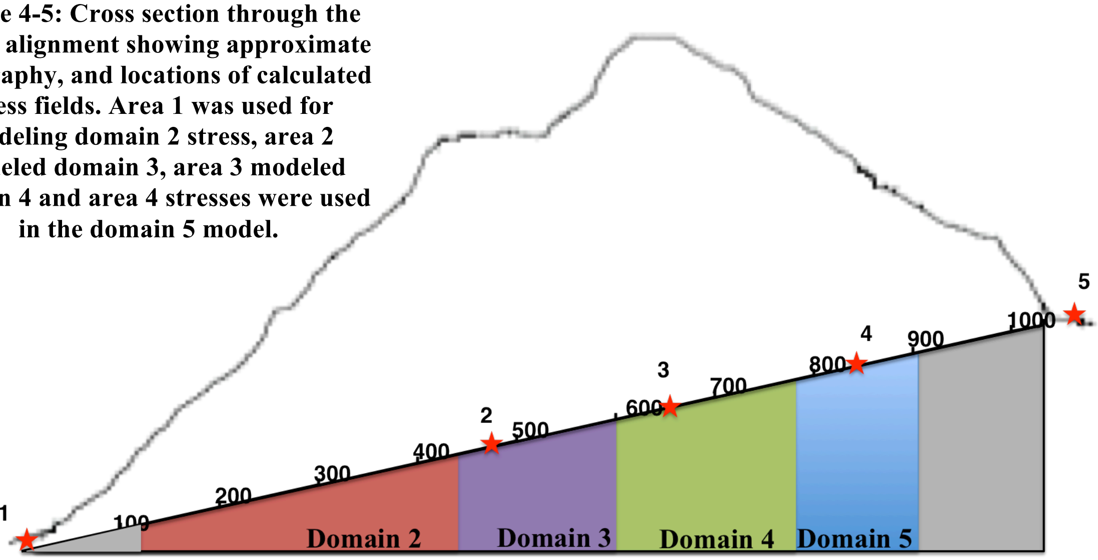
In order to properly simulate in-situ conditions, a number of different stress and boundary conditions were used. Gravity was specified as $10m/sec^2$, in the negative Z direction. All boundaries were given velocity values of zero, which fixed the model in space and stopped the model boundaries from moving or deforming when stresses were added. In-situ stresses were also added to simulate the natural stress that the rock mass would be under due to topography.

Although it is highly likely that tectonic stresses would also be acting on the rock mass due to the proximity of the Alpine Fault, these forces were not modeled in these cases, due to the difficulty in determining the magnitudes and directions of such stresses without in-situ testing.

4.3.3.1 Stress Field Derivation

Stress fields were created for five locations along the tunnel alignment, in order to get an idea of the change in stress with varying topography. A 2D elastic finite element stress analysis was undertaken using Phase 2, making a simple stress analysis through geometries perpendicular and parallel to tunnel alignment (Rocscience, 2011). This was undertaken to find values for σ_x, σ_y, σ_z, τ_{xy}, τ_{zx} and τ_{zy} with topography variations between domains.

Figure 4-5: Cross section through the tunnel alignment showing approximate topography, and locations of calculated stress fields. Area 1 was used for modeling domain 2 stress, area 2 modeled domain 3, area 3 modeled domain 4 and area 4 stresses were used in the domain 5 model.



The locations of these five stress fields can be seen on the cross section in Figure 4-5 and on the topographical map in Figure 4-6. Figure 4-5 also shows how these stress fields were matched up with the structural domains being modeled. Table 2 shows a summary of the calculated stresses.

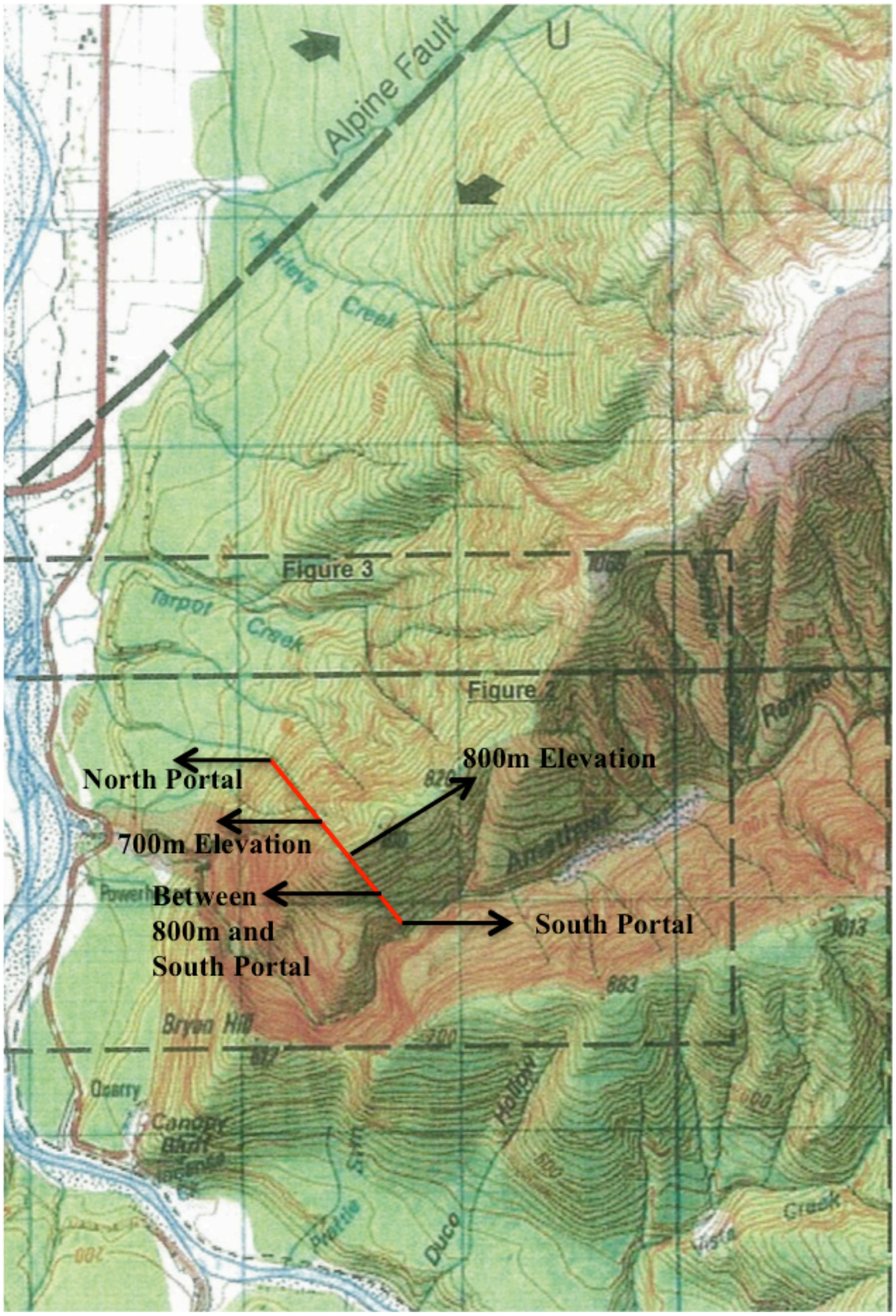


Figure 4-6: Topographical map of the area showing the tunnel (red) and the locations of the five calculated stress fields.

Table 4-3: Calculated stress fields for the five areas shown in Figure 4-5 and 4-6.

Location		**Normal Stress (Mpa)**			**Shear Stress (Mpa)**			**sigma v / sigma h**	
Area	Structural Domain	σ_h (cross-section, x)	σ_h (long-section, y)	σ_v (z)	τ_{xy}	τ_{zx}	τ_{zy}	K (long-section)	K (cross-section)
1	2	-0.9	-2.7	-3.7	0	-0.3	-2.26	1.2	4.6
2	3	-2.1	-1.9	-7.3	0	-0.5	-0.7	3.8	3.3
3	4	-3.2	-1.8	-9	0	-0.7	-0.1	5	2.6
4	5	-1.3	-1.7	-6	0	-0.6	-0.5	3.6	4.8
5	Not used	-0.8	-1.4	-2.5	0	-0.3	-0.6	1.8	3.1

After these boundary conditions and stresses had been implemented to the model, the model was equilibrated, or until change in displacements approached zero. After this, the displacements were reset to zero to prepare the model for tunnel excavation.

4.3.4 Excavation

Once the model had been run to equilibrium and the displacements reset, the tunnel region that had been defined earlier was excavated. In addition, the joint and material normal and shear stiffnesses were softened from their higher values used during initialization. The model was stepped 20-40 times (varied between domains), which was sufficient to start seeing movement of the blocks.

4.3.5 Model Outputs

Each domain needed to be stepped varying amounts before visible movement occurred. However, all the domains had the same overall trends of movement geometry, velocity and displacement. For this reason the following figures are the best examples of outputs generated from all four domains, and the full set of outputs can be found in Appendix F.5.

4.3.5.1 Geometry of Movement

The continuity and persistence of the schistosity were shown to have a large overall effect on the movement of blocks within the rockmass. Figure 4-7 shows domain 3 at step 478 where the blocks have begun to move and are visibly popping out of the invert and falling from the crown. This is exacerbated in Figure 4-8 where the same domain model has been stepped a further 10 times, and movement is clearly visible.

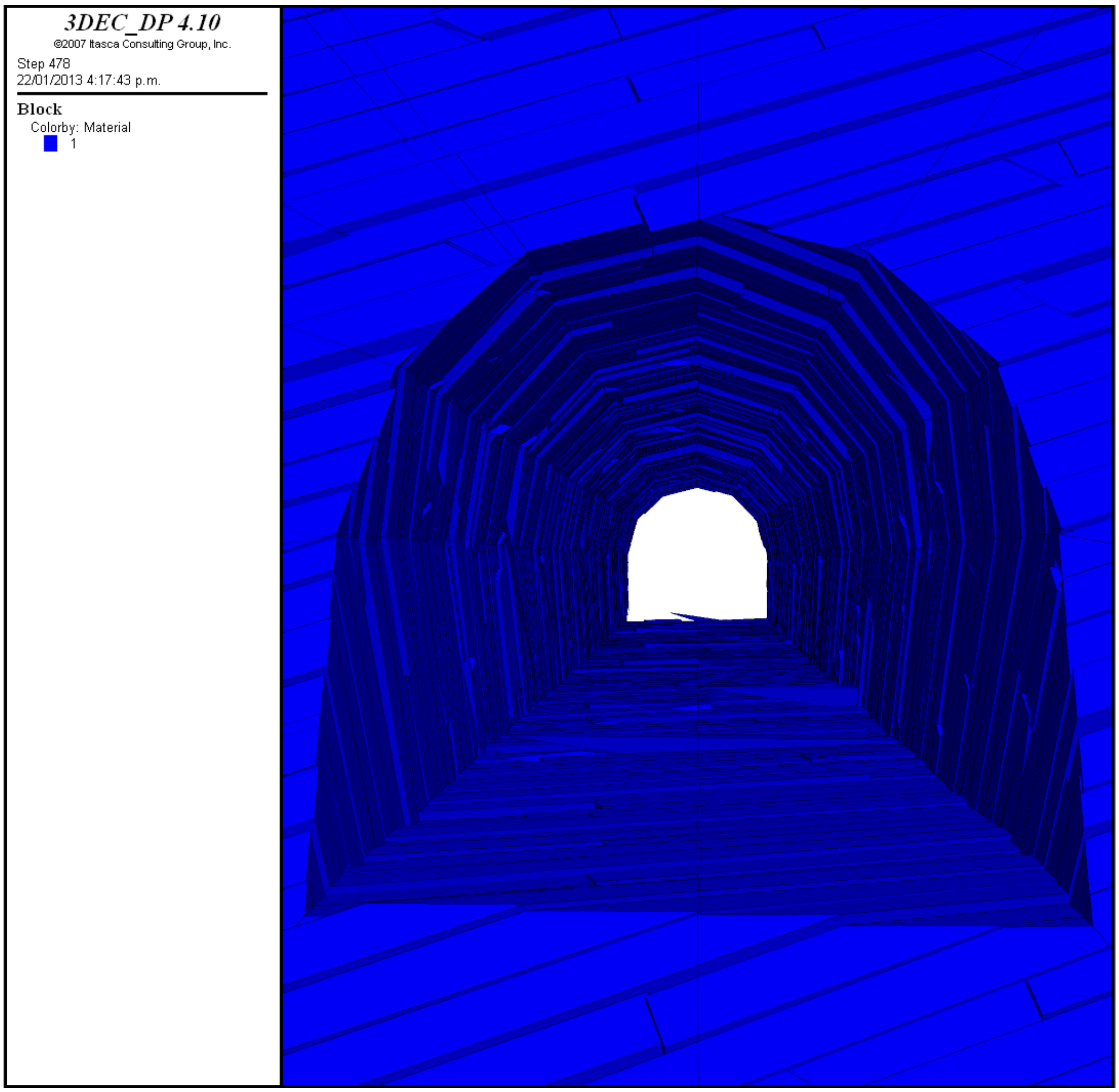


Figure 4-7: Domain 3, step 478. Blocks are starting to fall from the crown and are being pushed up from the invert (red arrows).

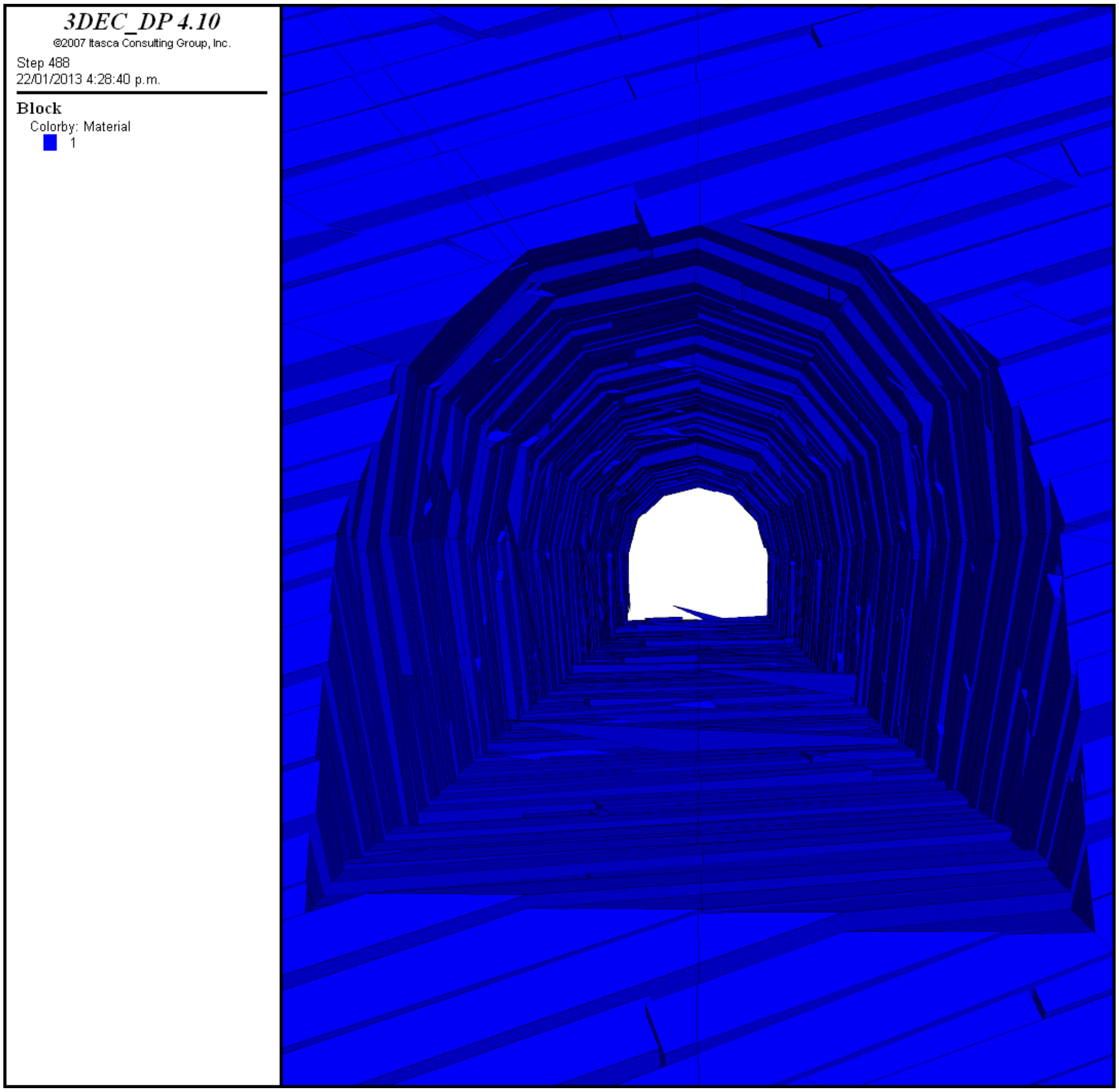


Figure 4-8: Domain 3 step 488. Movement has increased from Figure 4-7.

Figures 4-7 and 4-8 also show that due to the dip direction of the schistosity, the right wall of the tunnel seems to have more blocks moving out into the tunnel, whereas the left wall the blocks are angled into the wall so less likely to fall out. This was observed in the tunnel through the asymmetric nature of over-break which occurred in the crown, meaning the right side of the roof was more angled due to blocks falling out of this area preferentially during blasting. It was also observed within the tunnel that the schistosity was forming the main block geometry and size in the tunnel, and the joints were acting as cut off planes allowing the blocks to break off and release. This is shown from modelling of Domain 2 in Figure 4-9, and as it was observed in the tunnel in Figure 4-10. This is important, as it shows the impact the schistosity has on controlling the geometry of failure within the rockmass. Without the schistosity, blocks may be less likely to fall or would be larger and wouldn’t fall out as easily. This can also be seen in Figure 4-11a where the effect of the rockmass with only Schistosity has been modeled, and can be compared to the rockmass modeled with only joint sets 1 and 2 (Figure 4-11b).

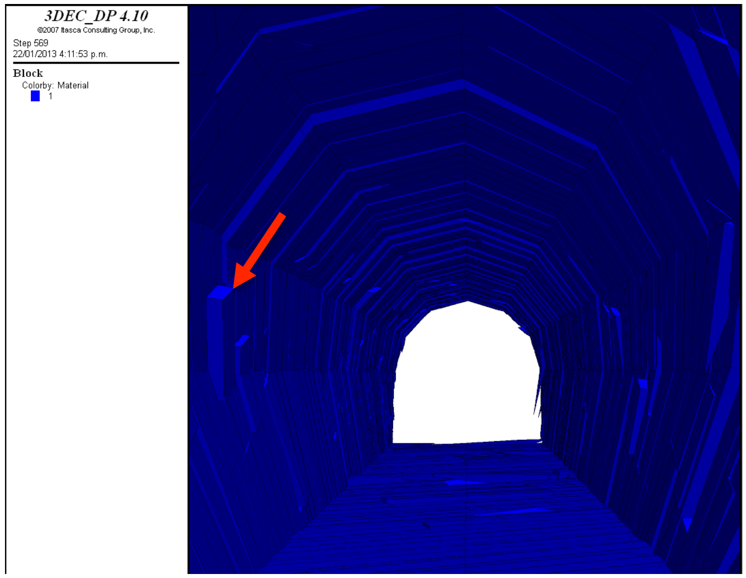


Figure 4-9: Domain 2 model close up showing the joints acting as release planes for schistosity bounded blocks.

Figure 4-10: Joint surface acting as a release surface for a schistosity bounded block. White line is 20cm.

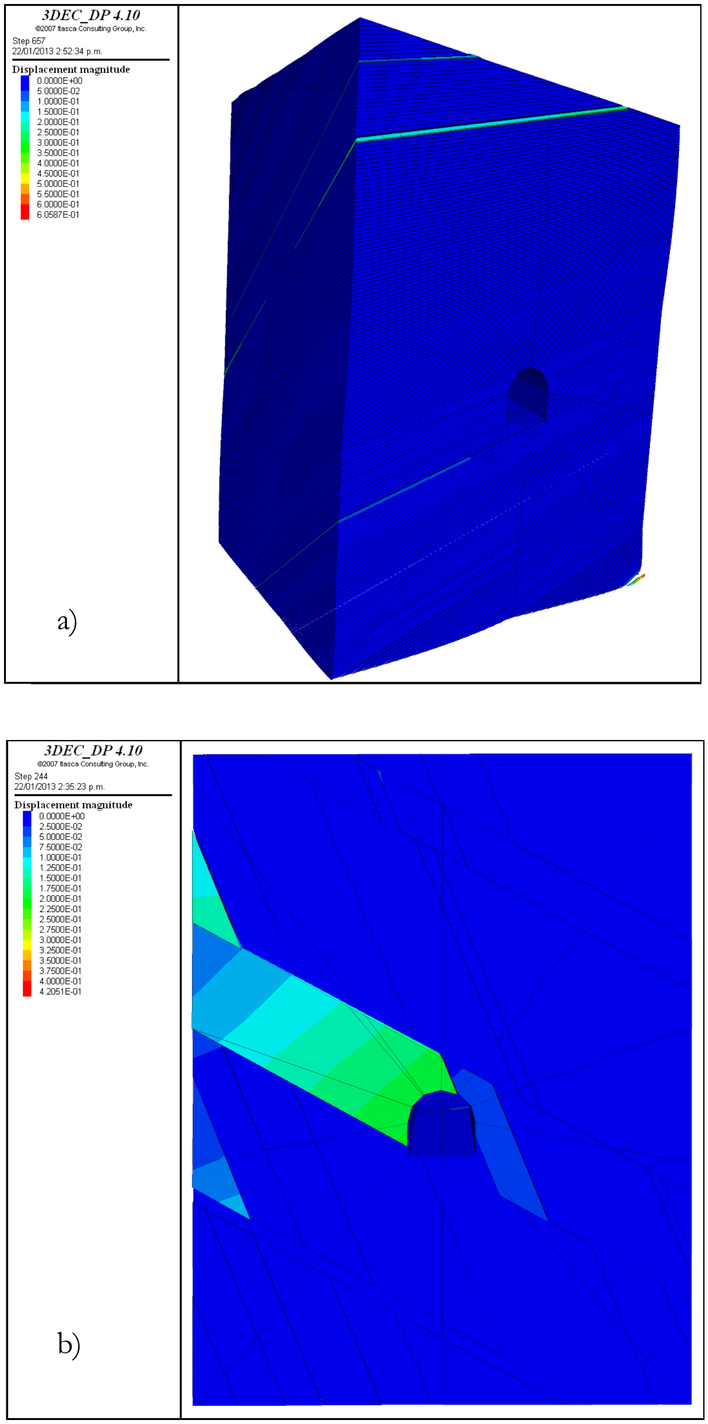


Figure 4-11: Screenshots from 3DEC showing the rockmass: a) without joints and b) without schistosity, and the displacements after the same number of steps. These images reinforce the influence schistosity has on controlling the block size and therefore the ease with which these smaller blocks move.

Figure 4-12 shows the scale of the blocks capable of moving. The side view shows a 20m length of the Domain 4 model. These blocks are relatively small – less than metre scale. The movement of blocks within the crown of the tunnel could not be verified for most of the tunnel due to the support used (shotcrete and rock bolts) and the ventilation bag, which obscured the natural rock. However, after a fresh blast, it was possible to see that the roof was quite irregular due to these smaller blocks breaking off during blasting, making a perfect profile difficult to achieve. It was also visible through the shotcrete in some man bays that the roof irregularity was controlled by the schistosity. In these cases, 'ridges' of rock with pits of over-break between were observed where a joint had released a block, which had slid out along the schistosity.

4.3.5.2 Displacement, Velocity and Joint Slip within the Rock Mass

The domain models were contoured so the amount of displacement and velocity of the moving blocks could be shown (Figures 4-13 and 4-14). The displacement contours (Figure 4-13) show that more displacement is occurring in the crown and right rib due to the orientation of the schistosity. Highest rates of displacement are occurring in the invert as shown by the vector plot.

Velocity contours and vectors (Figure 4-14) show a similar trend with high velocities in the invert and the right side of the crown (which causes the asymmetric tunnel profile). There also seems to be some displacement and movement in the left rib below the spring line, which shows that the orientation of the schistosity is not enough to keep these blocks from moving – this was also noted in the tunnel where over-break was still present in the left rib, but more pronounced in the right rib.

Figure 15 shows a joint slip plot showing that most of the joints within the rock mass are actively slipping, and some are moving in tension.

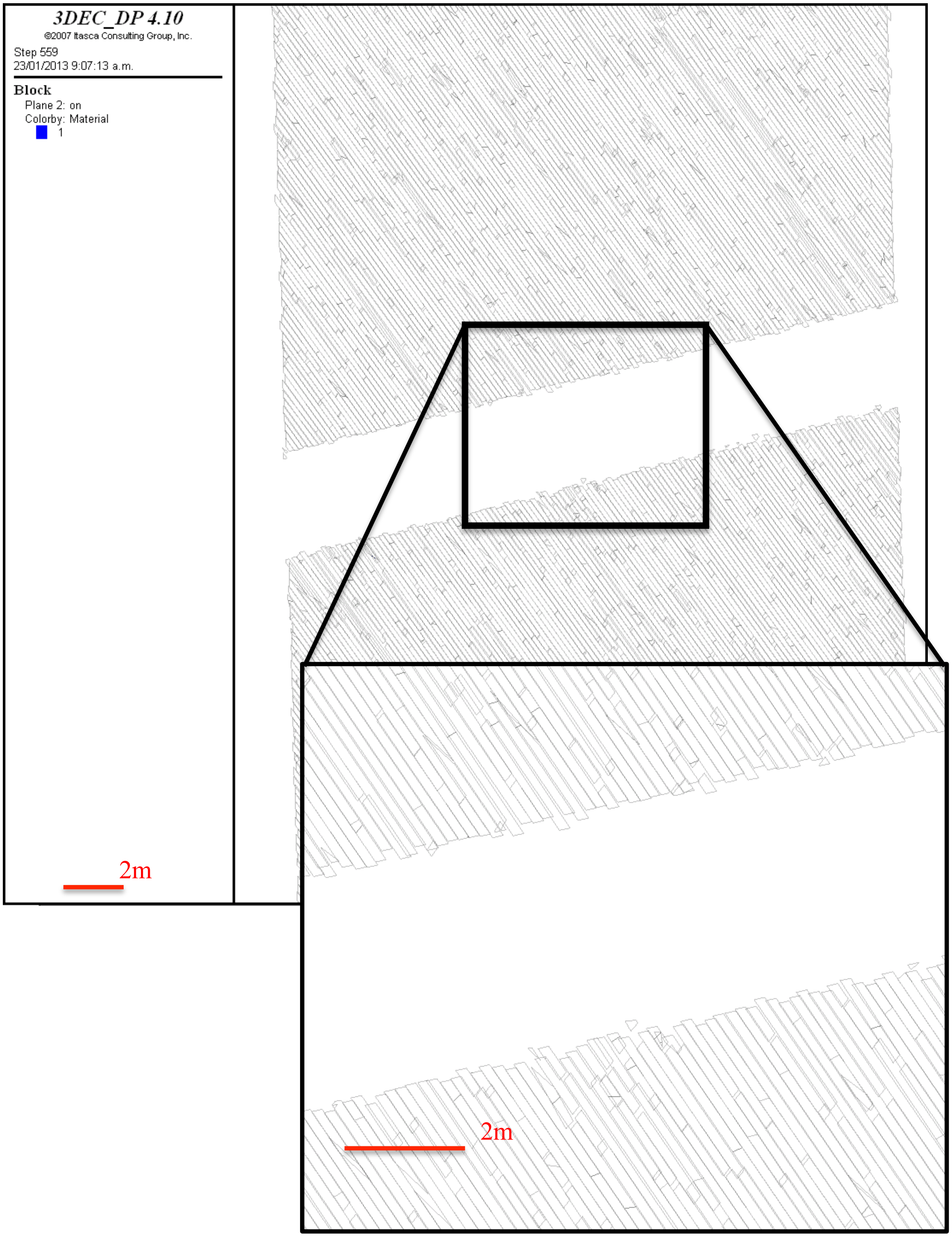


Figure 4-12: Domain 4 longitudinal cut away showing the tunnel in cross sectional view down its axis. Blocks can be seen falling out of the crown and popping up from the invert.

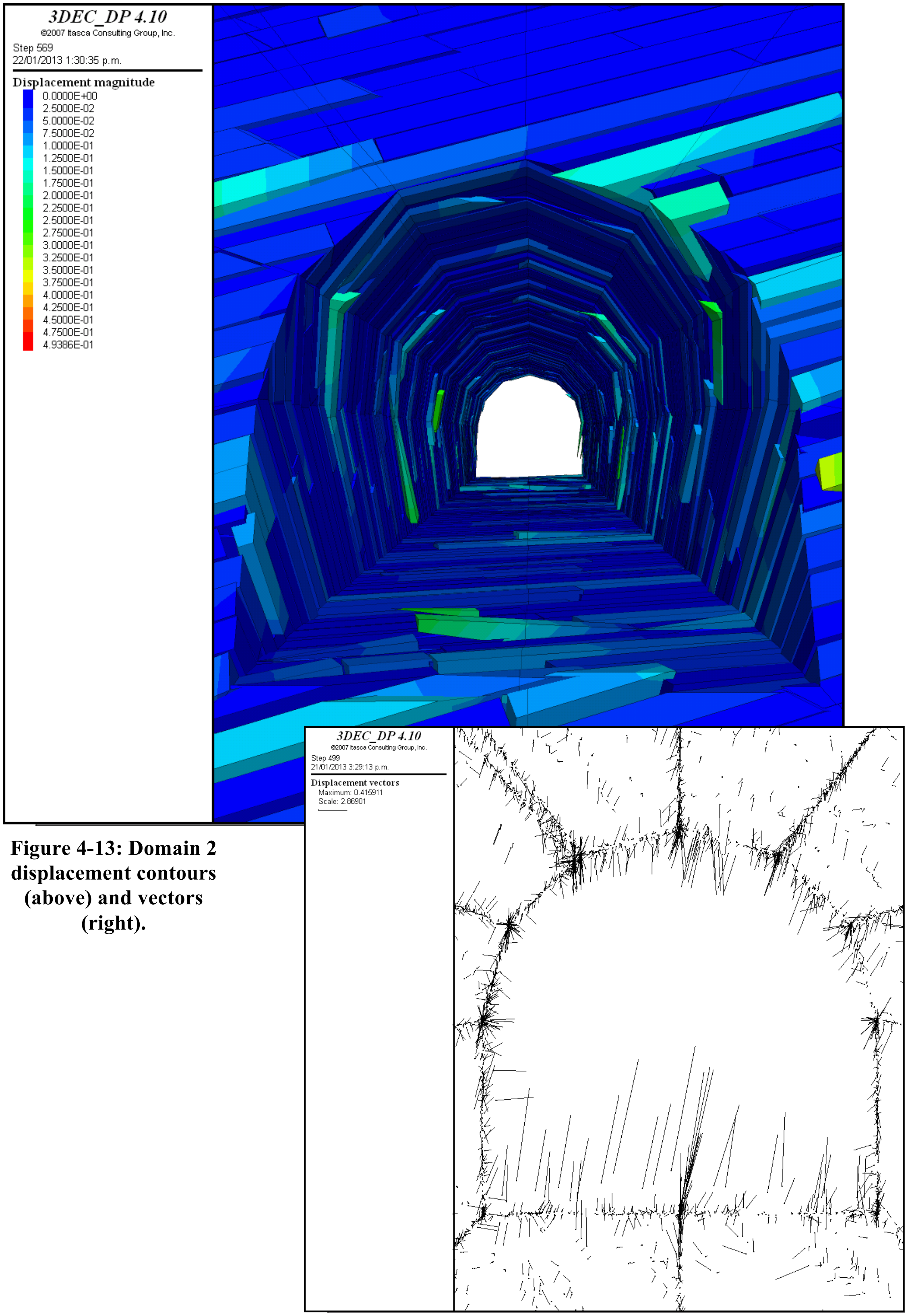


Figure 4-13: Domain 2 displacement contours (above) and vectors (right).

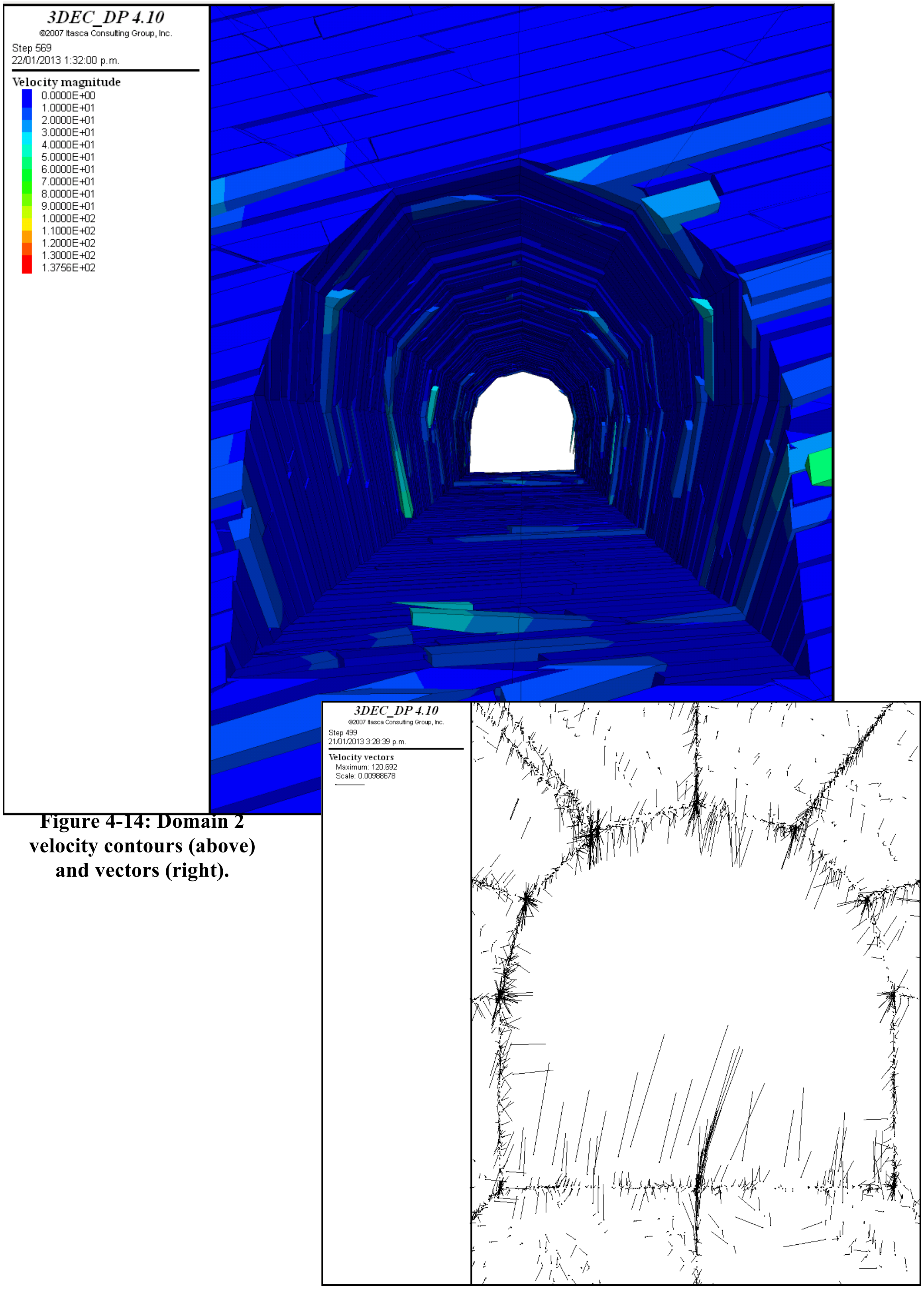


Figure 4-14: Domain 2 velocity contours (above) and vectors (right).

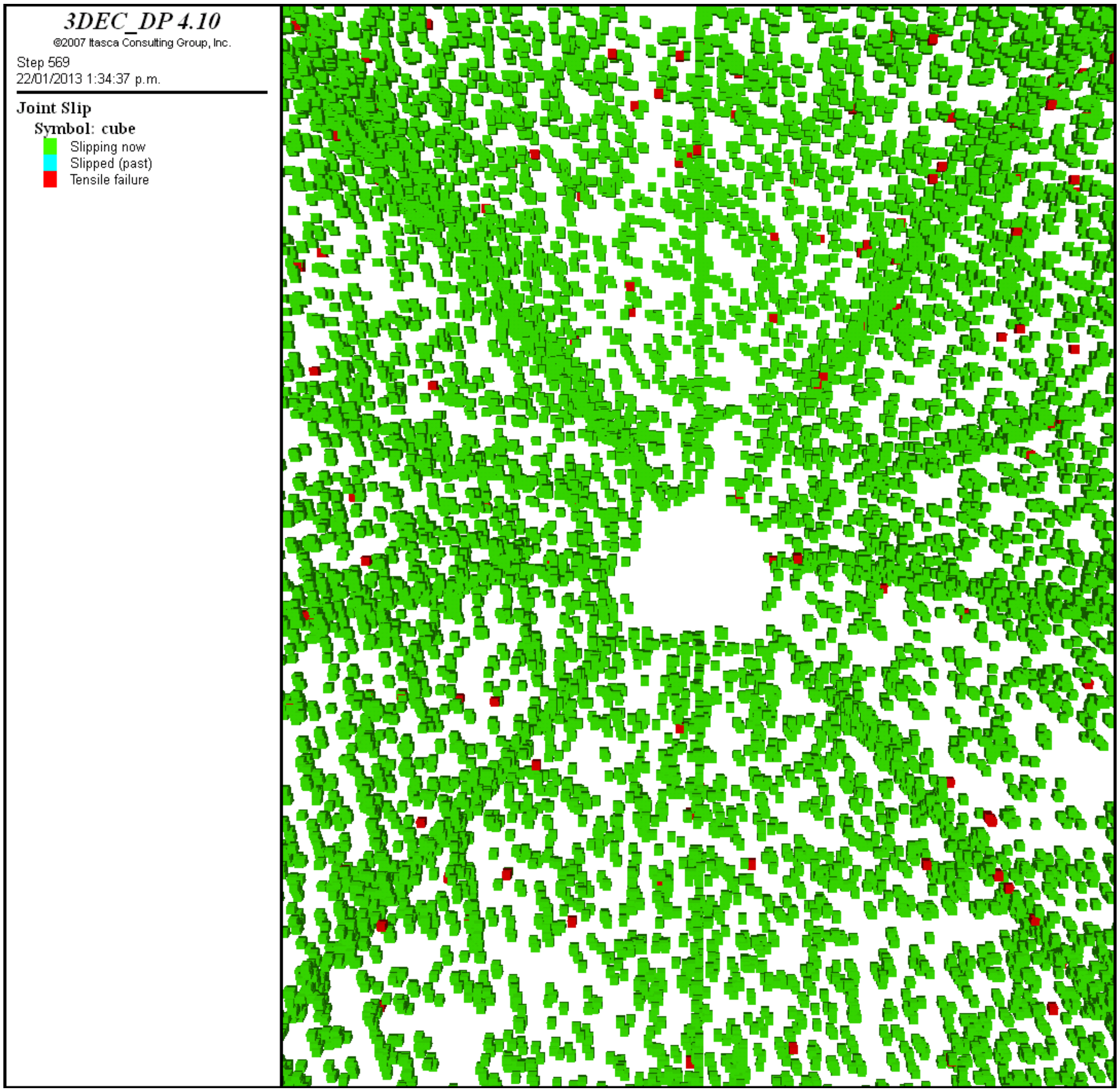


Figure 4-15: Joint Slip from Domain 2 showing that most joints are actively slipping.

4.3.5.3 Deformation History

The deformation history of the model (Figure 4-16) shows visually what was explained in section 4.3.4 and 4.3.5.1. The model is originally solved to equilibrium where unbalanced forced decrease over time until they approach zero. After displacements have been reset to zero, and the tunnel has been excavated, it can be seen in Figure 4-16 that the unbalanced forces increase as the blocks move into the empty excavated space. The amount of deformation that occurred between the different domains varied slightly, and depended on how many steps were run.

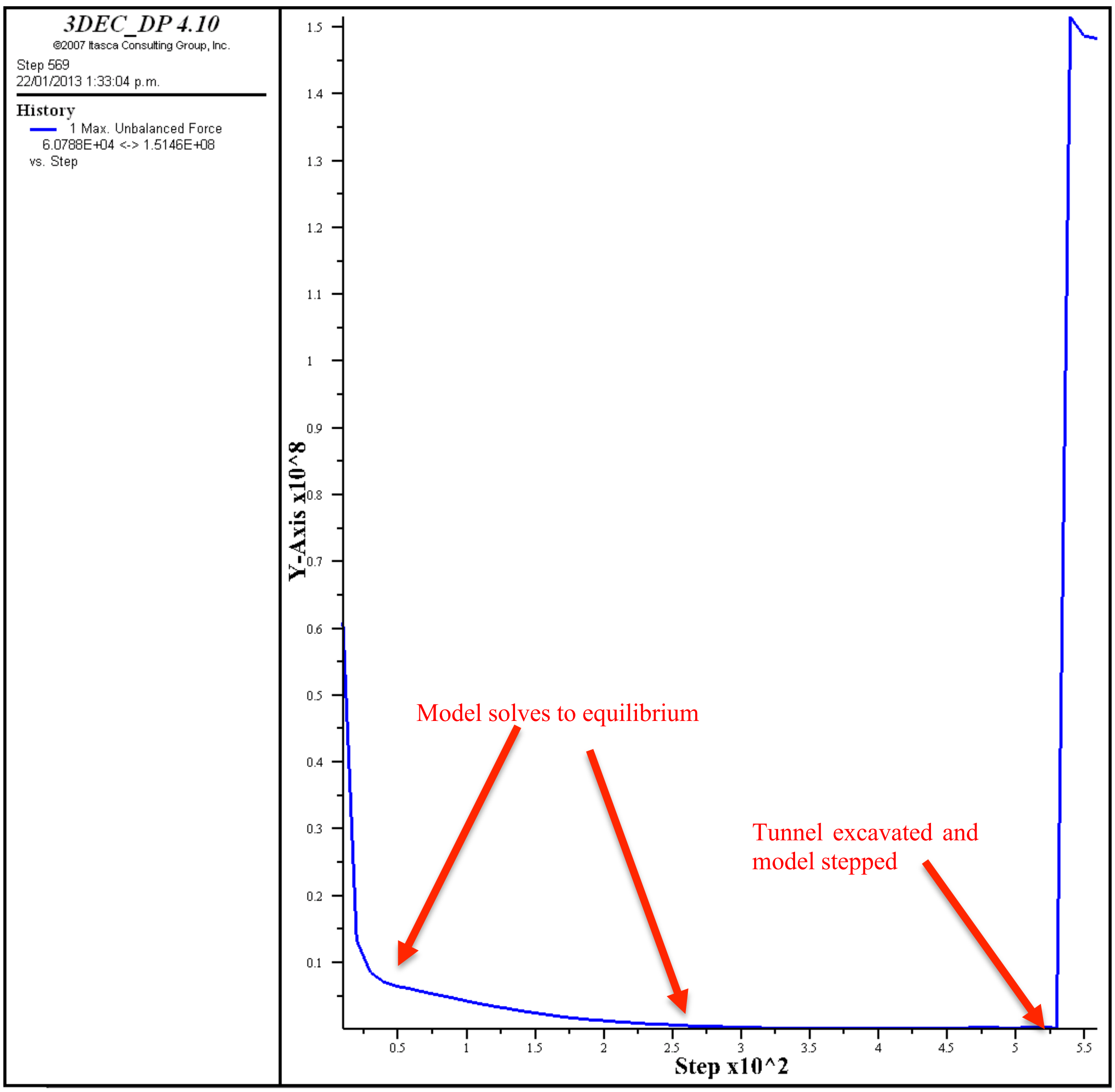


Figure 4-16: Domain 2 history of Unbalanced Force throughout the model.

4.4 Discussion and Synthesis

4.4.1 Limitations

The aim of modelling is to produce the most realistic conditions possible in order to most accurately simulate the rockmass and its behaviour during tunnel construction. In this case, there were a number of reasons that the rockmass generated in the model was not exactly the conditions found within the field. The model used rigid blocks instead of deformable blocks. This means the Poisson's ratio effect is not modeled. It is unknown how much of an effect Poisson's ratio would have to the rock mass, but it is possible squeezing and deformation of the blocks could cause clamping of joints due to extension, which could prevent sliding.

The tunnel geometry modeled is very simple and does not include any man bays or other such features, which exist in the tunnel. This was done due to the need for only a general understanding of the overall geometry of movement of the rock mass and this sort of problem would be included in a more in depth model.

Tectonic stresses were also not included in this model. There are undoubtedly regional tectonic stresses on the area due to the proximity of the project area to the Alpine Fault and the Amethyst Ravine Fault, and the schistosity orientation changes themselves are probably a function of these stresses. However, in order to get accurate measurements for these, a much more in depth stress field derivation would need to be undertaken. This type of model would probably also include the shear zones observed, as these would have a large impact on the overall rock mass strength. This was not necessary for the purposes of this, as the main purpose of the model was to investigate block release and sliding. Tectonic stresses may have clamped some discontinuities and reduced movement, but relative movement was investigated in this model rather than absolute movement involving all components of the rock mass.

4.4.2 Model Findings

The model used was suitable for the purposes of finding out how the rockmass moves and what failure types are most likely to occur. It was found that the invert section was most likely to pop up in all of the domains modeled. The right wall above the spring line was prone to falling out (high displacements and velocities) and the left wall below the spring line exhibited high displacements and velocities.

The use of pre-cast concrete segments in the invert was a decision undertaken by the contractor in order to control the flow of water within the tunnel (water flowed along groves in the concrete and was channeled to one side) and to mitigate the effect of wear and tear to the invert from machinery. The schistose nature of the rock and the low strength biotite foliation layers was prone to degradation under the repetitive loading of machinery intrinsic to a tunneling project of this nature. The effect of water scour also aided in this break down. The models for all domains show a clear trend for a large portion of the rockmass deformation to take place in the invert, and due to these pre-cast segments, this could not be verified. The need for these pre-cast segments at all could suggest that there was some deformation of the invert occurring, which aided in the breakdown of the invert. This would have been difficult to separate from machine-induced breakdown, however. The pre-cast segments in places have been broken and have experienced differential settlement, and again, it is unable to be concluded whether this is from excess water, machine break down, pop up of the invert due to stress, or a combination of the three factors.

4.4.3 Implications for Support

Figure 4-12 shows the scale of blocks capable of moving over a 20m section of Domain 4. As most of the blocks are under 1 metre in size, it shows that a support class using rock bolts with spacing greater than a metre will not have much effect on this form of failure. As introduced in Chapter 1 and illustrated by Figure 1-6, the tunnel used a number of support classes based on the Q value of the rock mass. These classes are shown in Table 4-3, and are made up of a combination of plain shotcrete, steel fibre reinforced shotcrete (various thicknesses), rock bolts and cable bolts.

Depending on the quality of the rock mass and the scale of deformations possible, a lining type support method such as a layer of shotcrete and/or mesh in affected areas (right rib above the spring line, left rib below the spring line) may be more effective than using rock bolts at discrete points. Hoek notes that even a thin layer of shotcrete can effectively support wedges when applied correctly, due their often large exposed surface area (Hoek 2007b). However, these options will not affect overbreak as they are installed after excavation. The overbreak is an intrinsic issue related to the geometry of the discontinuities within the rock mass. Chakraborty found the strength of the formation and joint orientation critically affected fragmentation and overbreak in a model study of blasting (1994). Support will prevent progressive failure of loosened blocks exposed at the excavation boundary (Hoek 2007d).

The fact that the model shows the invert is highly capable of deforming shows that a pre-cast invert lining was probably the most effective means of support for this area of the tunnel. It is difficult to tell how this will last over time and may need to be maintained, but this would be a recommended solution for the invert deformation issue.

With the use of blasting for the excavation of the tunnel, it is reasonable to expect a degree of blasting damage, including structurally-derived overbreak, which may affect the tunnel profile. Blasting can lead to a rougher tunnel profile due to loosening of blocks, and can easily extend several metres into the rock (depending on blast quality) (Hoek 2007d).

Mechanised tunneling, however, may produce a smoother profile and may lead to less ground deformation due to the almost immediate application of support (Zhao, Janutolo, & Barla, 2012). Marinos illustrates the necessity to take into consideration both the failure mechanism and the applied stresses to fully optimize support, as is illustrated in his study on two different ground types (brittle failure and plastic squeezing) and how their behaviours reacted to different support types (2004). The brittle zones had similar geotechnical parameters to the Amethyst project, and it was found that installing support as soon as possible after excavation provided the best protection against unraveling.

Table 4-4: Table of support classes used within the tunnel depending on the calculated Q value.

Tunnel Support Type	Rock Mass Classification Q Value	Support	SFRS in place Steel Fibre Concrete
Tt1A	>2.0	None	0
Tt1	>1.0	50mm thick plain shotcrete above springing line	0
Tt2	1.0>Q>0.4	50mm thick SFRS above springing line, and 1.8m long bolts at 1.5m centres in crown (three bolts per ring), rings spaced at 1.5m intervals along tunnel.	40kg/m^3
Tt3	0.4>Q>0.1	75mm thick SFRS above springing line, and 1.8m long bolts at 1.2m centres in crown (five bolts per ring), rings spaced at 1.2m intervals along tunnel.	40kg/m^3
Tt4	<0.1	100mm thick SFRS above and below springing line, and 1.8m long bolts at 1.0m centres in crown (seven bolts per ring), and one cable bolt at the base each wall, rings spaced at 1.0m intervals along tunnel.	55kg/m^3
Tt5	Initial Portal Section	150mm thick SFRS above and below springing line, and bolt pattern as per Tt4 support, excluding cable bolts unless ordered	55kg/m^3

Chapter 5
Summary and Conclusions

5.1 Project Objectives

The Amethyst Hydro Project is located approximately 4.5km east of Harihari in South Westland, New Zealand. It was constructed to secure the supply of power to residences in South Westland following a rise in tourism and dairy farming in the area. The project involves a 1058m long tunnel connecting the Amethyst Ravine to the Wanganui River and a 7MW power station. This thesis provides an engineering geological characterisation of the rock mass encountered during tunnel construction with a 3D numerical analysis of the failure mechanisms within the rockmass. The principal objectives of this thesis were:

1. To carry out an engineering geological field investigation to determine relevant geotechnical and engineering geological parameters for the Amethyst Tunnel. Scanline mapping of the tunnel length, along with re-logging of exploratory boreholes and strength testing of rock samples to give quantitative data which may be used for stability analyses.
2. To nominate structural domains within the tunnel for numerical modelling. The orientations of structural features (shears, schistosity, and joints) within the rock mass are the most important features in the assessment of tunnel stability, through both block geometry (shape and size) and through the nature of instability (i.e. block failure versus ravelling). By calculating mean orientations for different structural features, it is possible to predict representative failure types kinematically and to numerically model these.
3. To assess the effect on the rock mass of the nearby Alpine Fault and any changes in the geometry of structural features or rock mass conditions with increasing distance from the fault.
4. To numerically model the representative structural domains present in the tunnel and analyse behaviour of the rock mass during tunnelling.

5. To provide recommendations to optimise support in this rock mass and assist in planning of future projects in similar rock mass or geotechnical conditions.

5.2 Engineering Geological and Geotechnical Investigations

5.2.1 Field Investigations

Field investigations consisted mainly of a period of scanline mapping the dominant geologic, structural and hydrological features within the tunnel. Core logging of existing core was also undertaken. These investigations produced the bulk of the data used to define the engineering model, and provided unique information on the characteristics of the rockmass, for use during modelling. It was also found during field investigations that rock mass classifications carried out on the rockmass using two different classification schemes yielded varying results, and this was further investigated during the development of the engineering geological model.

5.2.2 Laboratory Testing

Laboratory testing including unconfined compressive strength, point load, and seismic velocity tests, which were undertaken on a number of samples from the tunnel. Although the results were sufficient for the engineering geological model needs, the data set would have benefitted from being more comprehensive. Due to the spacing of defects however, the block size was often too small to obtain samples large enough for testing. Samples were tested with both foliation parallel and perpendicular to applied stress direction. It was found that the rock was stronger when foliation was oriented perpendicular to applied stress – this occurred in both the point load and unconfined compressive strength tests. Seismic velocity testing was also undertaken with foliation oriented both ways. Unfortunately, due to levels of background noise, only one test was successful, and due to this test having foliation parallel to wave propagation direction, the intact rock is likely to have a higher velocity than what the rock mass as a whole would exhibit. This means the resulting Poisson's ration and Young's modulus may be overestimated, providing only an upper-bound estimate of seismic velocity for the rock mass.

5.3 Engineering Geological Model

5.3.1 Rock Characteristics

The first and most important part of the engineering geological model is determining the characteristics of the rock mass. It is important to understand the associated impacts of these characteristics on the overall stability of the rock mass and it's ability to perform appropriately for the required project. It was found that the Amethyst Hydro tunnel was constructed through two lithologies – debris flow deposit and Alpine Schist. The main lithology – Alpine Schist – had the most impact on the behaviour and performance of the tunnel.

Debris flow deposits were found at the west portal of the tunnel (where construction began). Due to the heavy support used in this area to prevent the lower strength material from failing, minimal investigation was undertaken on this unit. It is unknown exactly how far into the tunnel this rock type continues, but until at least 70m, the rock is described as softer, more highly weathered and in places 'colluvium'-type material. By 70m chainage, the rockmass is Alpine Schist and remains so for the remainder of the tunnel. Various degrees of metamorphism are encountered throughout the rockmass, but it mainly can be classified as grey, medium grained, well-foliated schist with distinct quartzo-feldspathic and biotitic banding. It has an approximate strength of 48-68MPa (moderately strong) and varies from slightly weathered to fresh.

5.3.2 Structural Model

It was found that the defects throughout the rockmass were the most significant in terms of affecting the stability of the rockmass. Large clay filled shears were having the most impact, as these drove down the strength of the surrounding rock and were also often associated with water due to the clay. These shears were classified as domain 1 of the structural model, as these areas could be anywhere from 30cm wide up to 1.4m in one case.

The rock mass away from these shear zones was found to be affected by schistosity and the two major joint sets that made up the rest of the defects present. These had varying apertures and infills, but the orientations of the schistosity were observed to change at regular intervals along the tunnel. The changes in schistosity orientation provided the breaks between domains 2, 3, 4 and 5. These changes were often associated with a large shear zone, and although no reason for the changes in orientation was found, it is possible that this is related to the Alpine Fault, the Amethyst Ravine Fault and associated regional tectonics. The dip of the schistosity was observed to steepen towards the Amethyst ravine fault, and the association with shears could be showing some regional dragging as the hanging wall of the Alpine Fault is uplifted and dragged over the footwall.

5.3.3 Hydrological Model

The hydrological model was linked very closely to the structural model, in that the large shears from domain 1 seemed to be controlling the water ingresses into the tunnel. These appeared to control pockets of stored water, which released on drilling, creating high water pressures in places. Spikes in water volume also occurred in the shear zones associated with the boundaries of domains 2, 3, 4 and 5.

5.3.4 Rock Mass Model

In the case of the Amethyst Hydro Project, the rockmass model had few patterns and changes within it compared to the structural and hydrological models. This is because one main lithology was present throughout most of the tunnel. Weathering did not vary much through the tunnel, and likewise strength changes were not observed during testing (although more comprehensive testing may result in variations being observed). Areas of higher metamorphism and gneissic banding were present, but these were localized and at too fine a scale to impact the model as a whole. These zones seemed to be related to a higher strength and slightly more intact rockmass.

5.3.5 Rock Mass Classification

Two classification systems were used –Q and RMR_{89}. These were both recorded at 5m intervals in order to compare results. It was found that the two systems weighted different parameters differently, and often did not align. Analysis of the parameters causing these disparities showed that the Q value had a tendency to underestimate the rock mass quality in the jointed rock mass, while the RMR_{89} was often more closely aligned to the conditions observed. This was likely due to the RMR_{89} including the orientation of defects in its calculation, and the effect of changes in block sizes. As shown during modelling, changes in block sizes can have a large impact on the type of behaviour that occurs, and this was a vital component of this rock mass. It is noted, however, that in order to most accurately classify the rock mass, different schemes should be used depending on the way they classify different parameters. Q was appropriate for classification of the sheared zones of domain 1, while RMR_{89} was more appropriate for the areas where pervasive schistosity controlled the rock mass behaviour, as in domains 2, 3, and 4.

5.4 Numerical Modelling

5.4.1 JointStats

JointStats analysis was undertaken to analyse the raw data and calculate statistical parameters such as persistence, average joint spacing and frequency. Joint sets 1 and 2 were analysed to find their average dip and dip directions, which supported the values obtained from stereonet analysis during structural domain investigations.

5.4.2 3DEC

Once the data had been analysed, 3 dimensional distinct element models for domains 2-5 were prepared. A simple block cut with joints and schistosity was used to simulate the rock mass. Rigid blocks were used, so no intact strength parameters were added into the model, due to the inability of the model to calculate the deformability of very small blocks. Additionally, the due to the density of defects within the rockmass, the behaviour expected was rigid block fall, not failure through intact rock, so a rigid block model is appropriate. The tunnel was excavated through this rockmass once the initial stresses were equilibrated, and then the individual domain models were stepped in order to determine how the rock mass behaves during tunneling in the simulated conditions.

5.4.2.1 Modelling Results

Although four domains with different schistosity orientations were modeled, it was found that they all had similar types of failure. The place most prone to high velocities and displacements was the invert, where blocks popped up as the first stage of movement in all domains. This type of movement was unable to be verified as the contractor laid pre-cast segments in the invert, to protect against wear and tear from machines, and to help control water flow and protect the invert from scour. The movement and deformation of the invert blocks may have lead to acceleration of wear and tear, combined with machinery use, but this is difficult to ascertain. The invert slabs have since settled differentially in places, and this may be due to deformation of the rock mass.

The right rib above the spring line showed high displacements, which were due to the angle of the schistosity and the ease with which blocks could fall in this area. This was evident in the tunnel, where an asymmetric profile was prone to occur after blasting, also due to the schistosity. The left rib beneath the spring line also had high displacements and velocities. The schistosity seemed to be the most influential defect type in all domains, and the two joint sets acted as releasing planes along which these blocks were able to move. This could be verified in the tunnel, where these releasing planes were common features wherever over break occurred.

5.5 Recommendations

Modelling identified the small block size present within the rock mass, and the localized areas where failure is most likely to happen. For this reason, it was identified that halos of rock bolts on >1m spacing will have little effect in stopping discrete blocks from failing, and a more distributed solution such as shotcrete lining or mesh would be more appropriate in the affected areas to prevent progressive failure of loosened blocks. Domain 1 is also not appropriately supported using the designed support classes, as there is no allowance for behaviours inherent to these zones, such as shearing, squeezing, or excess water flows.

5.6 Further Research

In order to validate these findings and increase their worth, it would be pertinent to undertake more strength testing of the rock mass. Intact strength values would be useful to obtain in order to get a more accurate idea of the rock mass strength. This would allow for better simulation of the exact properties of the rock mass. Petrological studies on the rock mass would also be of value, in order to better classify different metamorphic zones within the schist and into the gneissose areas. Further regional structural development of this engineering geological model would also be useful, in order to understand in more detail the influence of the Alpine Fault and the Amethyst Ravine Fault on the rockmass and the effect these are having on rock mass stress conditions and defect orientations.

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Appendix A

A.1 Terminology

Crown The roof/ceiling of the tunnel

Discontinuity any significant mechanical break or fracture of negligible tensile strength in a rock (Priest, 1993)

Fault A discontinuity surface across which there has been shear displacement (Kearey, 2001)

Foliation A repeated or penetrative planar feature in a rock, which may be defined by fabric, compositional layering or pervasive fracture. Most commonly used for metamorphic fabrics e.g. cleavage, schistosity, gneissosity (Kearey, 2001)

Intact rock a continuum or polycrystalline solid consisting of an aggregate of minerals or grains (Bell, 1987)

Invert The floor/base of the tunnel

Joint A fracture on which any shear displacement is too small to be visible to the unaided eye (Kearey, 2001)

Joint Set A group of joints with a common orientation (Kearey, 2001)

Rock Structure The three-dimensional structure of discontinuities within a rock

Rock Mass Combination of intact rock and rock structure

Schistosity A foliation produced by deformation in which tabular minerals, coarse enough to be visible to the unaided eye, have a preferred orientation (Kearey, 2001)

A.2 Field Descriptions for Rock Material

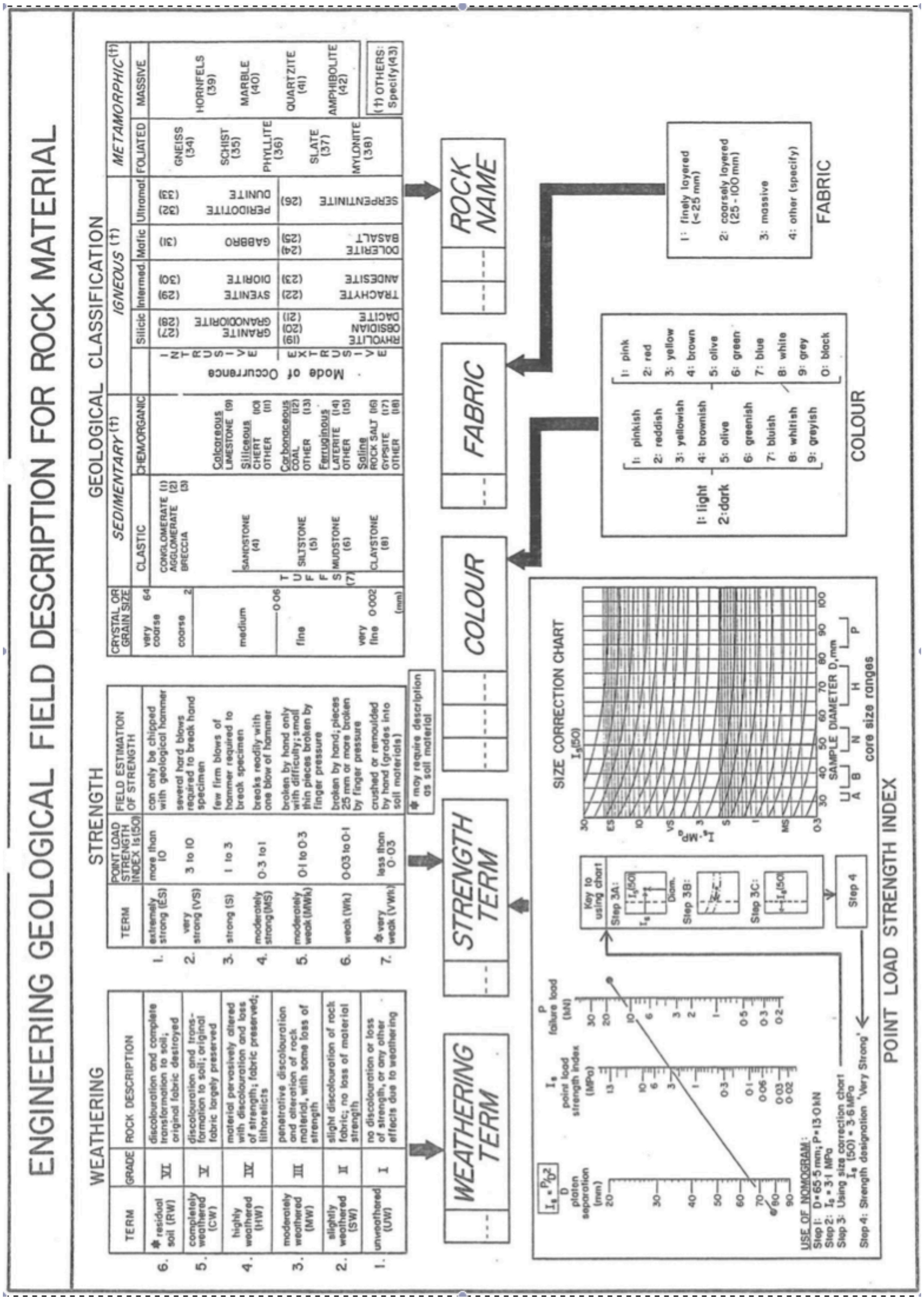


Figure A-1: Field Description of Rock Material (NZGS, 2005)

Appendix B

B.1 Daily Inspection Log (Geotech Ltd.)

Date	Chain age	Comment	Q	Q value parameters					
	End (m)			RQD	Jn	Jr	Ja	Jw	SRF
16-May-11		Q taken at 78.5m, rock quality very poor still (<10%), heavily jointed rock mass, wave shaped surface of joints, clay infilling in order of 5-10mm, large amounts of water coming out continuously from shear in face. Rock above shear that is sitting diagonally across face is unravelling just above this area.	0.04	10	15	1.5	8	0.33	1
24-May-11		Q taken at 92m, rock quality very poor but improving (10%), heavily jointed rock mass, wave shaped joint surfaces, stained surface of joints only, no clay infiling present, joints are tighter than before, water at face pooring out of weep holes, no high/low stress conditions observed	0.44	10	15	2	2	0.66	1
31-May-11		Q taken at 103m, heavily jointed rock mass (4 joint sets plus random), clay present in joint which cuts diagonally through face and splays off at bottom right, other joints have only surface staining present, medium inflow of water concentrated in drill holes. No indication of high or low stress conditions.	0.11	10	15	2	8	0.66	1
2-Jun-11		A lot of water coming out of face, not concentrated to once particular spot.							
7-Jun-11		A lot of water coming out of face, not concentrated to once particular spot, a part from this the profile is good.							
13-Jun-11		Q taken at 126m, RQD improving, heavily jointed rock mass, with smooth undulating joint surfaces, surface staining present in joints, majority of the face is damp with drips forming on the left rib. Shear surface with ~15mm thick grey clay orientatedd parallel to foliation, not causing any problems therefore not counted in Ja evaluation.	1.33	10	15	2	1	1	1
20-Jun-11		First signs of high stress conditions in left rib where chemical bay has been created, after this no signs of stress conditions (noted as just a localised area of stress, maybe due to the change in cut orientation for bay)							
22-Jun-11		Q taken at 140m, rock quality improved at 25%, three joint sets visible, smooth undulating joint roughness, slightly altered, sandy particles and surface staining present, ribs and face mostly dry (with some drips of water), high stress conditions noted a few meters back (noted on 20-Jun-11).	1.39	25	9	2	2	1	2

1-Jul-11	171.8	Q taken at 168m, three joint sets present plus random smooth undulating joints with max persistence of 1.5m, silty fraction with some clay material present within joints, face dry but a lot of water coming of of drill holes forward of face, stress conditions not an issue.	1.28	35	12	2	3	0.66	1
5-Jul-11	182.7	Q taken at 180m, rock quality improving, half barrels seen in roof profile, four joints present, dip/dip directions including: 70°/049, 40°/310, 64°/257, and 58°/294. Smooth undulating joint surfaces, silty with small clay fraction in joints, medium to high inflow of water, drilled ahead to make a conduit for water to drain on. Meduim stress conditions, no sign of relaxation in rock mass. interpretation of ground that we have moved through appears to be a wider sheared zone, start was a band of ~500mm wide pulverized water training- high % quartzose schist at ~163-165m chainage (parallel with foliation), at 170m chainage there is a ~2m wide zone where slickenslides were present along a joint in greenschist (see photo from the 6-July-11), several joints at ~90° to the foliation area concentrated within this smaller zone containing ~5-20mm thick bands of orangey brown clay. There appears to be alteration of the schist giving a gneissic appearance (see photos).	0.44	30	15	2	3	0.33	1
12-Jul-11	201.4	Q taken at 200m, rock quality vairable ranging from 20-45%, 3 joint sets plus random including: 50°/300, 64°/296, foliation at 48°/134. Smooth undulating surface, silt and clay fraction in joint infilling, small amount of water coming out of left floor, no evidence of high or low stress conditions. Greenschist and pink quartz alteration appears to be reduced, foliation at ~190m was 44°/154. The overall rock mass is variable withe a mix of gneissic compositional layering between the biotite and quartz; with quartz layers up to 15mm. Some areas were rock is very competent with large ~250mm block length. Joint in roof controlling profile laying on a low diagonal angle making the roof sqaure.	0.56	20	12	1	3	1	1
18-Jul-11	216.60	Hit water in top of roof after advancing forward at 214.5m, when night shift started and advanced again to 216.6m it was obvious that ground conditions have changed. Dave J documented a loss of shotcrete due to "too much water present". Q taken at 214.5m, rock quality was variable across transect area, very hard 50 MPa in some places and then shattered along foliation in other areas. Three joint sets plus random, sub verticle joint in tunnel rib 85°/234 (dip/dip direction), smooth undulating surfaces, sandy clay coatings, large inflow of water coming out of roof, no evidence of stress problems. Past this point water increased substaintally.	0.37	20	12	2	3	0.33	1
19-Jul-11	219.80	Water control began, drilling back from the face through the shotcrete to intersect and divert water out by. Mesh, split sets, and 1.8m bolts used to support rock as loss of strength in areas of rock due to water interaction. Problems with bolts not installing due to too much water. Ground in roof becoming softer and less competent, water influence on stability of roof.							

20-Jul-11	222.40	Split sets and mesh used to ensure stability while moving forward, water coming out through foliation not only through joints, WM instructed probe holes to be drilled to control water by creating a conduit. During night shift roof has gone up approximately 2m, poor ground conditions and water making it difficult to get bolts in and set with the resin.							
21-Jul-11	222.40	Did not move forward in tunnel due to conditions. Installing supplimentary support.							
22-Jul-11	222.40	Did not move forward in tunnel due to conditions deteriating, tunnelers spent day supporting the roof with supplimentary support. Sub-verticle joints seen in ribs show approximately 300m dispacement on either side, clay infilling present, and water still coming over of roof.							
25-Jul-11	225.20	roof unravelled over the weekend due to the washing out of the sub verticle joints, and with the combination of water pulled out bolts with it. Shotcrete was used to control the unravelling and stabilized roof, profile out >2m. The subverticle joint that started this was at approximately 219m, can see in roof the evidence of this joint and the impact it had on the profile. Drain holes that were initially drilled in back at approximately 210 m have started to drop off in quantity of water. Water at the face spraying out in small qauntities in some places.							
26-Jul-11	230.80	Roof back in profile, and shotcreted. Installed convergence pegs at 224.6m (1st area where roof was back in profile after unravelling over the weekend). Water still at face. Shear in rib and face with dip of approximately 42 degrees, and <200mm wide infilled with typical fault breccia material.							
27-Jul-11	233.80	Q taken at 224.6m, one block of intact rock within the transect line for RQD, the rest was mainly broken along foliation and low persistence random joints, orangy brown oxidation discolouration in foliation indicating water has resulted in loss of strength as well as the general rock mass of the schist. Sub-verticle sheared zones with ~300mm displacement in unravelling area, sheared joint at ~90° to foliation with a dip of 42° to the NW; with persistence of >5m, dispacement of >800mm with a wide band of >200mm thick course sand size matrix and matrix supported clasts i.e. typical fault breccia. Unfilled joints still present, smooth undulating surfaces of dark greeny grey coating. High angled shears not affecting the section in by of the convergence bolts but are still present, sheared joint at 90° to the foliation least favourable to stability at the moment, no rock wall contact when sheared on the surface, due to the spacing of this joint set greater thatn 3m added 1 to Jr. Large inflows of water, probe holes installed through roof and ribs, a decline in water from original probe holes back where the water first appeared. No evidence of stress affecting the tunnel.	0.23	25	12	2	6	0.33	1

28-Jul-11	233.80	Shear at 90° to foliation cross cutting face up close to the roof profile, water appears to be using shear as major conduit but not confining it. Shear causing roof to need to be taken above profile slightly. Using the jumbo head to scale out this material therefore not very competent, breaking along joints and foliation, overall this material is very shattered.							
2-Aug-11	246.90	high quantity of water in centre of face, caused problems for night shift shotcreting.							
3-Aug-11	249.70	Water in face still pouring out, face very jointed, orientation of joints variable and staggered. Major joint through face 62°/312. Foliation not prominent in some places due to gneissic texture causing variation of linearity (see photos).							
4-Aug-11	251.70	Problems raised with ground conditions, Q value suggests that we are in Tt3 conditions; but bolting clearly indicate that we need to increase groud support. Time taken for bolting is substaintail due to bolts not taking to the ground and therefore new holes need to be drilled or entire bolts needing to be replaced. Q Value analysed in the area of the convergence bolts; results show that we would be in Tt3 but probably not the case due to bolts not performing well in some cases and re-installation needing to be carried out.						0.33	
5-Aug-11	253.90	convergence monitoring from 4-5 August shows there has been a 1.1cm change overnight. This result could reflect the comment from 3-August regarding the bolts not taking in some places.							
8-Aug-11	262.30	Profile looking good, noticed some poor milling practice on the ribs, taking a while to drill out face. No cracks seen in tunnel during inspection. X3 cylinder samples taken of 480kg/m3 40kg FRS. Face looking dry, bit of water out of floor.							
10-Aug-11	265.90	Profile looking good, shotcrete went on well using the 420kg cement per m3, face looking very hard and dry. Having to replace teeth on milling machine due to hardness. X3 RDPs, tray, and X3 cylinders taken of 420kg/m3 40kg FRS.							
12-Aug-11	272.60	highly metamorphosed gneissic texture, very hard in some places, foliation very hard to distinguish. Q taken at 268.6m. Face dry.	1.11	20	12	2	3	1	1
15-Aug-11	278.20	Q value indicates the rock at lower end of Tt3 (0.2). Rock in face hard but brittle so good for blasting, rock mass has broken mainly along the joint sets in the face rather than being foliation controlled. Face is relatively dry, there is a weeping of water on the left hand rib. There is one main sheared joint through the centre of the face which is planar (no slickenslides seen), above the shear the foliation is very steeply dipping causing the face to be almost at right angles to the drive, below the shear the foliation is dipping at ~52 degrees. After blasting the lower section of the face did not pull very well, and was proud of the upper face by ~0.5-1m.	0.22	10	15	1	3	1	1
16-Aug-11	278.20	no movement forward due to ventilation being switched from 600-1000mm bags.							

17-Aug-11	280.30	rock in face hard but brittle, rock mainly breaking along joints, when drilling out the face on left side approximately 400mm below the springline; drilling water was squrting out of the hole above ~100mm below the springline. Two shears running through face, appears to be running almost horizontal with some variation. convergence bolts were installed but not measured due to cycle.							
18-Aug-11	281.60	Rock in face hard but brittle, gneissic texture present. Rock mainly breaking along joints below the springline and both foliation and joints above when blasted. Two shears running through face, appears to be running almost horizontal with some variation. convergence bolts measured before and after blast, no change was seen.							
22-Aug-11	293.30	Face dry, no evidence of stress, lots of oxidation seen in joins and through foliation reducing overall rock mass strength. <10mm thick grey gouge along foliation oreintation still present reducing rock strength. Joints present 58°/308 (~90° to foliation), 62°/26, foliation at 52°/160.							
23-Aug-11	293.30	Q taken at 293m, rock quality variable, joints and foliation are controlling rock mass, overall the face looks a lot more muddled and less blocky than the last Q was taken. Four main joints plus random visible, joint surfaces are in general rough and irregular but the overall surface is planar, joint spacing of <1.5m with a silty clayey infilling along with surface staining which is very prominent in this area, both through joint surfaces aswell as through foliation surfaces, these oxidation surfaces are reducing the rock mass strength with some part of the rib been able to scrap out with fingers. The face is dry with no water coming out of the floor. There is no evidence of stress effecting the tunnel. The foliation is at 50°/180, orientations of joints include 70°/118 to 68/120, 48°/128, 72°/302.	0.67	20	15	1.5	3	1	1
24-Aug-11	295.80	No movement forward, installing floor panels (same as yesterday).							
25-Aug-11	298.30	Charfy's blast from last night came out very well, half barrels visible in roof and ribs (above the springline), face is dry all over. Foliation present but surface variable from smooth and planar to undulating with a gneissic texture; with thick compositional layering becoming apparent. Some weak zones within the foliation present, clay layers running parallel with foliation reducing the overall rock mass strength. No evidence of stress conditions affecting tunnel, some cracking of shotcrete just below the springline where the shotcrete becomes thinner and small blocks may have come loose while shotcrete was at early stages of setting (occuring approx 10m back from the face).							
26-Aug-11	301.30	Charfy's blast from last night produced a great result, half barrels in roof and ribs, all projecting at the right angle! The rock in the centre of the face looking very hard and competent, left lower rib looking less hard/broke out easier, maybe due to the angle we are driving at. The face is dry, no water visible at the floor. The overall profile is looking good, it was noted from last night that the shotcrete that went on was crumbly							

		but on close inspection looked good this morning, maybe some setting problems again? check after weekend. The joints in the face are still a bit muddled and hard to make out (not very blocky).							
29-Aug-11	303.10	Face and ribs dry. Tunnel is forward approximately <4m from where bogging bay finishes. Rock mass in face very strange, foliation is not prominent over the majority of the face, there are 3 prominent shears cross cutting the face, 2 shears which cut the face at a low angle diagonal and have close spacing (<300mm in some places) have just a thin infilling of silty clay material, the third set is sub verticle and shows quartz infilling. The face profile is good, with the profile maybe being a bit wide on the left. The tunnel has been shotcreted right up to the face.							
30-Aug-11	306.8	Installed convergence bolts at approximately 300m mark (just after bogging bay), the first main round had been pulled in the bogging bay since day before, in this area we are tunnelling sub-parallel to foliation, so far with bay in approx. 2m it is standing up ok, there are no signs of stress acting against us in this drive. The cut that was pulled however is a bit messy but hard to tell how much was pulled due to the muck pile still mostly remaining in the bay, the face of the bogging bay is uneven, this is probably due to us driving sub parallel with the foliation. The face of the main tunnel drive was drilled partially last night and the rest this morning; with Paul Silke noting that they had trouble with every hole in the face, and that he thought the face was "rotten" in the center and the LHS fell out while drilling. A suggestion was made that they should only fire to the springline due to the nature of the ground and the joint sets present. Measured convergence bolts after blasting. Could not get a clear look at face due to muck pile in the way.							
31-Aug-11	309.3	Men mucking out after having to blast a part of the face in the middle floor section that did not come out the night before. Still having trouble with dets, whether it is due to misfires or cut off's have not yet come to a conclusion. Rock material at face appears to be hard and competent, but there are joints present that are causing issues and making it hard to load the face up due to holes dropping in with material, this is making the process of loading up the face very difficult. Mucking bay is blasting well. Convergence monitoring was carried out after blasting in the afternoon and there was no movement from the previous day identified; indicating that the profile is standing up well with the current conditions and location of bogging bay.							
1-Sep-11		Face is dry. Men having trouble with loading holes, due to holes not completely staying open. Mucking bay progressing, stability good with orientation of drive. Q value high, RQD still variable but improved.	1.90	30	4	2	8	1	1
7-Sep-11		Face and profile in shape. Men still having trouble with keeping the holes for loading fully open. The mucking bay has been finished, shotcreted and bolted up, very tidy job. Setting up for installation of floor panels today; the floor conditions are dry so should not have trouble. Face is dry. Foliation prominent in face,							

		clay layer >5mm parallel with foliation present in lower face, this is not causing any stability problems at present. Over all good conditions, Q value would be likely to be +1.							
8-Sep-11		Face not moved forward until end of shift. Sampled shotcrete used in floor filling (x3 cylinders).							
9-Sep-11		Charfy's shift shot panels and tray for coring, problems with shooting. Mix looked right, very dry worm came out of shotcrete hose at one stage but the rest of the mix looked good. Angle of shotcrete machine down ramp onto portal platform possibly causing some of the pumping problems that were experienced, the machine looked as if it was struggling to pump the mix.							
12-Sep-11		Face dry, no evidence of stress, the majority of face looking competenet with RQD still variable (>20%), 3/4 of the face up to just above the sprinline foliation is controlling of the conditions at the face, above this face is muddled. Joint in left rib (looking up) controlling tunnel drive for ~4m (~1m back from face), very flat planar joint with little variability of orientation. ~10m back from face shear cutting at approximately 90 degrees to foliation has had considerable alteration to the foliation, the foliation on the upside of the shear is dipping at at higher 46 degree angle and then below the foliation is dipping at a much lower __ degree angle, foliation change in orientation only localised to several metres of deformation. Men having trouble with the motor in the shotcreting pump which controls the oscolation of the nozzle, replacement found in spare parts in Arnold's shed.							
13-Sep-11		First thing in morning shotcreting delayed due to water pump at tunnel portal not working properly, and shotcrete pump not being cleaned out correctly the night before. 1st batch of shotcrete taken samples of but no Glenium was added to this mix. Profile in tunnel looking a bit out, maybe due to joint in left rib controling profile still. Face is dry.							
14-Sep-11		Profile at face looking really good, shotcrete possibly a bit thin on the walls, Joint in left rib which is controlling the tunnel drive profile for approx 4m (86°/48) with the strike running approximately parallel with the tunnel orientation. Day one of water at the face. RQD in face is variable, four or more joints present 52°/222, and 42°/312, in general the joint roughness is smooth to undulating with a small silty/clay fraction of infilling, greeny infilling present in face, water running out of face through drill holes, water present up to approx 400mm from apex/roof. No evidence of stress affecting the stability of the face or ribs.	0.59	20	15	2	3	0.66	1
15-Sep-11		Face very blocky, water at face same as day before. Oxidation indicates that a lot of water has passed through this area. Rock mass over all is competent and hard. Foliation clearly visible in face.							
16-Sep-11	360.7	Face very oxidized, water only coming out of ~1m below the springline, with the rest of the face dry. Two main joints in face (see photos), both dipping diagonally across face; with one at a steeper angle then the other (the steeper of the two 58°/296). Face over all very blocky, the lower angle joint in roof controlling							

		profile. A lot of clay in face, in joints and along foliation where water has been present before. All bolts in roof (x25) went in first go, didn't have to redrill any.							
19-Sep-11	353.9	Lower 1 m of the face is wet to runing with water, the rest of the face is dry. Whole face is very oxidized, browny orange in color. Joints and foliation clearly defined in face and ribs. Men working at cleaning floor and drainage conduit down tunnel. Bay for little digger has been drilled out (approximately 240m-235m?) in right hand rib. Cracks in wedge at mucking bay don't appear to have moved anymore, gark marks on shotcrete very obvious. Over weekend men have not moved forward, problems with the installation due to cable being damaged on installation. Men drilled out and fire at night.							
20-Sep-11	356.6	Charfy fired a round last night, profile looks great, well shaped especially on the arch. Water in roof and out of face. Water appears to be controlled by high angled sheared zone (looks to be dipping with foliation). Shear at approx 354m. Foliation orientation is variable grading to almost subverticle near the face. Water quantities would be medium, with the main difficulty created by the water now coming out of roof. No evidence of stress affecting the stability of the face/ribs. (see face log for illustration of this).							
21-Sep-11		Installed pins approximately 3m back from face, the face is very wet along with ribs and roof. Water is definitely controlled by Sheared zone which was visible in roof and still is in ribs. Profile is good overall.							
22-Sep-11		Face damp, everything else very wet/water pooring out of roof, need to drill holes in roof to contain water in roof and ribs. Profile good considering the amount of water in roof. Charfy had a lot of problems with loading the face due to water and then had misfires with the 50 non el delays. Convergence monitoring near face at 8am, no significant movement since measurement from day before.							
26-Sep-11		Water in tunnel has slowly reduced away from sheared zone at ~354m, the face at present: above the springline is dry, below is medium to high flows of water. Sheared zone that contains water runs along foliation (previously thought it ran at a higher angle), foliation at variable angles. The shear would be classed as no rock wall contact before 10cm shear, the infilling is a fine thick light greyish blue clay. Schist through the chainage since last documented is a mix of very weatherd to unweathered, with the overall rock mass being very blocky. The schist at the face is competent, would have a high compressive strength (>40MPa), sigmoidal folding seen in foliation (see sample). RQD variable (~20%), joints in face appears to be clean (no infilling in joints), mostly a bit of oxidation. Men installing floor panels and having a lot of trouble dealing with the amount of water that is in the floor. Later in day loaded face, again having trouble loading the lower half due to excessive amount of water.							
27-Sep-11		Less water than at the face yesterday (approximately 3/4 of the face is wet). Medium quantity of water coming out. Joint in rib measured to be 52/60 (dip/dip							

		direction).							
28-Sep-11	381.1	Face a lot more shattered than yesterday, face wet but not running above the springline, face wet and running below the SL. Material in the face easily removed with head of jumbo. RQD has reduced over the last 2 days. Tunnelers needing to spend a lot of time at face loading holes. Another clay band present in face (~horizontal cross cutting the springline mark).							
29-Sep-11		RQD dropped from previous days, material in face very easily removed by scaling with the jumbo drill head. Four main joint sets in face, very hard to tell due to gneissic texture being prominent in some places and not in others. Foliation 58°/ 152. smooth to undulating joint surfaces. Two sheared joints through face have simliar characteristics, lower shear with dip/dip direction of 56/179 (but in general variable orientations seen). Clay infilling with wall contact before 10cm sheared movement, >5mm thick singular clay band. All other joints in face appear to be unweathered to slightly oxidised. Medium qty of water in lower section of face (dry to damp upper section), reduction in water at face excavation seen each day.RQD is really affecting the Q, the rock in face is very shattered but cohesion in joints does not appear to be an issue. The face is a lot drier than what it has been over last 2 weeks, water appears to be dying away. Convergence pegs installed and measured before both the face and transformer bay was installed. Drilling out and loading up appears to be alot easier, do not know whether this is due to the water pressure or rock quality improving.	0.11	10	15	2	8	0.66	1
30-Sep-11		Face dry to damp, shears still present in the face. Hard to tell the quality of the rock at the face due to a shotcrete in way. Side drive from yesterday's blast came out very well, one area will need to be re-blasted to get full depth. No evidence that stress is affecting the stability of the drive, no cracks in shotcrete above or around drive that were obvious. Variability of the foliation apparent in side drive (see photos from this date in photo log). Side drive was wet before blasting, excavation dry though once the round was pulled. Convergence monitoring results showed ~6mm change in measurement with the SL. Report emailed around to all in the morning.							
3-Oct-11		Face dry. Torro taken to greymouth for service after mucking out first thing in the morning.							
4-Oct-11		Full face dry, rock mass very blocky, no evidence of stress affecting stability of face or ribs. Face oxidised/weathered to unweathered in places, no sheared zones or clay infilled joints in face. The profile was too narrow in some places, charfy's crew fixing these areas during day shift today. Torro arriving approximately 6pm. Convergence monitoring on the points at 379m, results show a total 12mm movement has occured at this section along the SL since initial reading. The transformer bay ~160-170m which was intalled after the initial reading was left unsupported for ~3 days which could explain the relaxation; however no signs of cracking in the shotcrete was evident and the pegs were competent in the walls.							

5-Oct-11		Face dry, profile looking good (mabye too wide). Face looks to be overhanging the drive. Butt holes seen in face, ground appears to be hard and competent, some oxidation still present in face but there is no sign that this is reducing the strength too much. Overall the face is very blocky, the foliation is schistose with little sign of gneissic texture. No signs of relaxation or stress affecting stability at face. Convergence monitoring first thing in morning showed no significant movement to the results collected last night. Conditions right for ANFO use. Real difference noticed with time taken to drill out face, could be a combination of water pressure improvement due to pump maintenance and/or the use of a larger more rigid drill steel (gradational steel from R32 to R38, i.e. the dril steel tapers to the head). Collected samples from shotcrete aggregates for sieving analysis tomorrow. Second lot of convergence monitoring carried out, showed no significant movement since this mornings measurement even though a round had been pulled. Round pulled last thing on day shift, one small bit on top left didnt fully come out, but overall a big round pulled. Rock material in muck pile very blocky of uniform size. Atleast 4 joint sets visible in face, stability good, everything looks to be holding together good. Very warm outside (~18 degrees), ventilation in tunnel working excellently. Noticed that last round of shotcrete has created a bit of shadowing- this area needs to be fixed.							
6-Oct-11		Face dry (same face chainage as last night)							
7-Oct-11		RQD less <10%, shattered and very weathered. Four main joints seen in face, foliation at 52°/144. Joints smooth to undulating, oxidized surfaces in joints and through foliation, clay free (supprising that I couldn't see any clay infilling, may have missed it due to really good scalling at face). Face is dry (with the exception of a couple of tiny drips out of the roof. No evidence of stress affecting the stability of the tunnel face or ribs.	0.666666667	10	15	2	2	1	1
10-Oct-11		Dry conditions. Roof profile gone up a bit over the weekend, the cause was most likely due to overloading the profile holes with ANFO. PD asked D. Jenkins crew to use the profiler product. During day shift R. Thompson set off the fire suppression system while climbing ontop of toro to check out something on the top. Fire suppression systems coming first thing in the morning to refil unit. Time delays related to this incident was several hours in total. Wheel bearing in front left of Batching plant gone, mechanics onto fixing this. Shotcreting was carried out before this was found. Can still use this machine for shotcreting as they can just fill up the sterling using the loader bucket at the base station, the men normally only use ~2m3 per shotcreting round so there should be no significant delay. x3 samples of from batching plant taken for UCS testing.							
11-Oct-11		Dry conditions at face, very blocky, one joint set in particular that is at low angles controlling the profile. There was a flat tire on toro which was noticed once bogging from the face was finished. The batching plant for shotcrete is still out of action from the front left							

		wheel bearing but men made up good brew to the same mix design in the sterling concrete mixer.							
12-Oct-11		Dry conditions at face, installed convergence pegs. Sterling used again for batching of shotcrete, x3 samples taken to fill in the paper work. Sample looked and felt like it had a really sticky paste and was consistent.							
13-Oct-11		Dry conditions at face, schistocity very prominent, there looks like there has been a lot of brittle movement in the face as there are folds which have been displaced at ~90° to the fold apex. This has created areas in the face and ribs which are completely shattered (RQD >10%) and others which have an RQD of ~20-30%. Joints are smooth to undulating, with a small clay fraction of infilling in some joints and high levels of oxidation still present in others, this seems to be only having a small impact on rock strength. Several joint sets still present in face and ribs. No water. No stress appears to be affecting the stability of the tunnel. Batching of shotcrete back to batching plant today. Round from last night pulled very well, profile looking more square, blocks in muck heap of more consistent size. Measurement from latest convergence pegs taken.							
14-Oct-11		Dry conditions at the face. Only a half blast came out from night before. Face almost leaning on angle with foliation. The men did not use enough ANFO by the looks of the large (~0.5m diameter) block lying ontop of muck pile. The action roof profile is good. Convergence monitoring on pins installed on Wednesday showed no significant movement.							
17-Oct-11		Dry conditions at the face. Q-Value carried out today. RQD variable, there is a band in line with the foliation along the lower section of the face approximately 150mm in length that is intact but over the other 99% of face RQD is <10%. Four main joints at the face, the foliation appears to be uniform at the face and ~1m back in the ribs. Joints slightly oxidised with a small fraction of clay infilling (but no noticible thick clay sheared zones present). No water at the face. There is no evidence of stress affecting the stability of the tunnel. Overall the profile looks good, and the face is on a safe and manageable angle. The Toro is currently the only bogger in operation. Drilling out time is still improving. A total of 26m was moved forward in the tunnel last week (Mon-Sun).	0.666666667	10	15	2	2	1	1
18-Oct-11		Dry conditons at the face. X3 shotcrete samples collected from batching plant. Men shotcreted in morning and then installing floor panels afternoon. Face looks good, in profile. Very prominent joint set in face (see photos from this day). Joint set repeated approximately 30cm apart (same as yesterday). Rock quality variable. Very thin (<5mm) sub verticle, sheared zone seen in left rib approximately 3m back from face. On either side shear schist was very soft but foliation still visible, persistence >1m, shotcrete covering upper area, undulating surface. Not causing any stability problems but worth noting as something that was not usually seen.							
19-Oct-11		After round was pulled water at the face during day shift, limited to a small area just higher than the centre							

		of the face. Water appeared to be coming out of a hole (suggested it looked like it was coming out of a bore hole which was unlikely due to the elevation we are at). The quantity of water coming out of the hole is medium to high. Shear zone seen in face. Men had a lot of trouble with shotcreting overnight.								
20-Oct-11		Face has not moved forward since yesterday afternoon on morning inspection. Water still coming out of the center but looks like over a larger area (~300 X 300 mm), still a lot of water. Sheared zone in face has thickness of >1m, most likely the same sheared zone picked up on the cores at ~289m. Sheared zone still retains visually alot of original foliation fabric but on closer inspection with a rod it is very soft. A hand sample of the material showed how shattered the gouge was. Light grey and white colouring with some lenses of dark-light grey clay. The actual sheared zone feels damp but is no running water coming out of it. The sheared zone is along approx. orientation with foliation. Water still coming out of upper central area of the face. Convergence pegs installed ~1m out by of sheared zone. See face log.								
21-Oct-11		Both underground bogging machines were out of service, sanvik coming to fix first thing. No movement forward in face.								
25-Oct-11		Labour weekend off. Both underground boggers out of service, sanvik trying to fix toro and find where leak is that was causing the problems. Shotcrete problems last week attributed to the silica fume quantities that were coming out, rate that it was coming through was too low. Water still coming out of face. Jinks' crew let off a round; this did not pull properly. Toro put back into action late afternoon. Slip above the portal where the mesh was holding up vegetation and a small amount of debris failed just before 5pm. Night shift went home due to poor weather conditions and a concern that more material above the portal would fail as a result of the heavy rain.								
26-Oct-11		After a H&S meeting in the morning to re-assess the situation at the portal a safe strategy was sorted for the removal of the material that had come down over night. There appeared to be no structural damage of the tunnel or the stabilization work done above the portal. No scouring was seen on the interface of the shotcrete and where the mesh was which was the main concern from last night. No movement forward in the tunnel occured. No night shift.								
27-Oct-11		Face half loaded from the day of the slip. Medium to high quantities of water coming out of in-by of the sheared zone. Measured sheared zone to 1.6m wide. Sharp contact on both sides of sheared zone confirmed. Split set acting as both support and conduits for water. Material within the sheared zone on the left hand rib has fallen out below the springline over the last couple of days. Convergence monitoring taken just before the sheared zone after peg that had been blasted out was replaced. Ventilation back on in tunnel. Power, air and water still being repaired at 3pm. Bogging out in tunnel the remander of any muck in bays and at face. No night shift. Graham, Jack and Ash out for most of the day with B-Grade courses.								

		Face scabbled and drilled out ready for loading. Medium to high quantities of water still coming from the completed section of tunnel back to 440m. LR fully shotcrete to floor from 444.5 to 447.5 and RR 443-451.5. Convergence monitoring taken showing no movement. Face comprising competent but very blocky rock from crown to floor with tight foliations but stability of face affected by close fractures running near horizontal across the face. Water pouring from the crown at the face and discharging from the drill holes as water tracks down the foliations. (John Easther comment)							
		Ground conditions similar with water discharging from all drill holes. 20 weepholes drilled in-by to control water flows. (John Easther comment)							
7-Nov-11		Water in roof, ribs and face. Ground conditions stable, profile looks good over approximately last 6m, no evidence of high stress conditions.							
8-Nov-11		Water in roof, ribs and face. A lot of oxidation draining through shotcrete and through drill holes in the face. Medium quantities of water coming out, water not limited to either joints or foliation (not controlled by any obvious structures. Rock is competent, half barrels in almost all of profile. RQD definately improved since last discussed (i.e. before the sheared zone). No evidence of stress affecting stability in tunnel. Drain filled up 208L in 9 seconds.							
9-Nov-11		Water in roof, ribs, and face. A lot of water coming out of the lifter holes in the floor. Last round in good profile. Installed convergence bolts. Shotcrete greater than 100mm thickness in areas where pins were installed. Rock quality much the same as previous day. No evidence of stress affecting stability at the face.							
10-Nov-11		Q-Value taken today (face only a couple of meters forward from convergence pegs with much the same ground conditions). RQD at the lowest is ~25%, with some sections in the rib displaying 30-40%. Four main joint sets visible in the face. Foliation orientation in dip/dip direction is 58°/158 (slight change since last orientation was taken). Surfaces of joint were smooth to undulating, rock wall contact present on all joints, unaltered with some surface staining only if at all. High quantities of water seen at face (possibly the highest we have seen). Water draining freely all over ribs, roof, and floor through foliation. Water has not appeared to drop off at all since we hit was after the major sheared zone. No evidence that stress is affecting the stability of the face, ribs, roof. Drilling out in the face not having any trouble dispite quantities of water, possibly due to the lack of clay infilling and the RQD improving from being very poor to poor on the Q value system.	1.1	25	15	2	1	0.33	1
11-Nov-11		7 seconds to fill up 208L drum of water.							
14-Nov-11		8 seconds to fill up 208L drum of water. Face still wet in lower half, damp above springline, still amounts of water in the floor which will cause problems for installing floor panels. Water not confined to any particular joint, coming out through foliation. Rock in							

		face competent, blocks larger in size (RQD improving). No clay seen in face, oxidation if anything seen on joint surfaces. 500m mark passed on night shift.							
15-Nov-11		Yesterday afternoon after they drilled out, water was present again all over the face. Half barrels seen in ribs ~2m long. Rock quality good, very blocky. Only surface staining in joints present. Drilling time good dispite amount of water.							
17-Nov-11		Full face is dry, floor still wet. Very rapid change in presence of water without any obvious geological constrants (this all points torwards the draining of a perched water table in the Amethyst Range). Water out by of face nearly all dropped off except for a few dribblers in the roof, floor still quite wet and is causing problems for the installation of floor slabs. Shotcrete in roof and ribs above the springline looks to be of a good coverage (>75mm). Rock mass blocky, RQD >20%, only surface staining on joint surfaces if anything at all. One joint set 62/278 in wall, not causing a problem. Four joint sets plus randoms present at face and ribs in total. No evidence of stress affecting stability at the face and ribs. Profile looks good.							
21-Nov-11		Face dry, a minor amount of water coming out of toe in face. Water out by dropped off, water still coming out of roof and ribs in oxidation zone through shotcrete (get chainage for this area). Last 2 rounds that have been pulled hit too hard in roof. Rock mass is blocky, there is a bit of oxidation weathering damage through some sections of the foliation present in the face, in general the rock quality is good and there is no evidence of unstable rock in the face/roof/ribs. One small sheared zone orientated along foliation in face, less that 5mm thick, greyish brown clay infilling. Notably a high quantity of biotite in the schist at the face, clear where water has been and started to break it down. No evidence of high/low stress conditions.							
29-Nov-11		No movement forward over last couple of days, drilling out face in morning to move forward before they start working on installing and replacing invert panels. Last 2 rounds and face profile looking really good. Face/ribs/floor all dry. Rock at face harder than what we have seen before, garnets prominent in the schist. Foliation tight, with little to no weakening induced by oxidation through the foliation as seen out by. RQD >40% in most sections of the face. Four joint sets seen in face, foliation at 58°/144, the most prominent joint set in the face at 50°/310; joint spacing ~1m ± 0.5m. Small sheared zone visible in right rib ~5m back from face (in morning) see photos, plane 66°/302 variable, clay infiling <5mm thick light greyish white in colour, pronounced weathering through foliation on either side of sheared zone (~0.5m on either side), small area fallen out on underside of shear; not affecting the stability of the tunnel small area of the rib only. At the face; joint surfaces smooth to undulating with variability from unaltered to slightly altered with surface staining. No evidence of stress conditions at the face/ ribs/ floor.	2.666666667	40	15	2	2	1	1
30-Nov-11		Men working on replacing old invert slabs, diverted water using the half drains up off the ground (see photos from 30-Nov-2011).							

1-Dec-11		Men working on replacing old invert slabs that have been damaged.							
5-Dec-11		Face, floor profile all dry. First round of the second bogging bay has been pulled. Floor panels up to date (~15m from face).							
6-Dec-11		Face, floor profile all dry. RQD very good (>50%). Rock mass still blocky with 4 joint sets visible. Foliation tight. Small amount of weathering within foliation only. No evidence of stress affecting stability at the face or in 1st round of new bogging bay. Rock is the best we have seen. Discussion about reducing the tunnel support method to Tt2.							
7-Dec-11		First day of Tt2. 3x 1.8m rock bolts,1.5m spacing in profile between bolts, 1.5m spacing between rings, and >50mm thick FRS. Face dry.							
13-Dec-11		New mucking bay: 1 main joint set controlling left rib (persistence of >2.5m), along with a very large profile area which hasn't quite pulled right, mucking bay all dry. Main Drive: minor amount of water coming through face in-by of a small (>10mm) sheared zone containing a light grey and white band of clay orientated with foliation. Foliation sitting at 58°/142 (D/DD) in face. Paul Silke has added shotcrete and a bolt to the wedge of the new mucking bay to increase support.							
15-Dec-11		Installation of another convergence peg on wedge so if any movement on this wedge occurs it will be seen, measurement this morning also taken. The face on Friday 16th December showed a change in ground conditions, the rock mass was very broken up and 4 joint sets plus randomly orientated sets where recorded. RDQ was measured at <10% in sections, with the overall Q value resting at 0.7. There was no clay infilling present at the face and water at the face was minor with only a few damp patches .	0.666666667	10	15	2	2	1	1
16-Dec-11		Convergence monitoring carried out in by of the 2nd mucking bay, found no significant movement in the values recorded.							
		Rock quality was poor for only several meters and then changed back.							
6-Jan-12		Rock quality good with Q resting at 3.3 RQD still variable but a minimum of 50% measured on the ribs up close to the face. Face was dry with droplets of water coming out of roof approx 8m back from face.	3.333333333	50	15	2	2	1	1
9-Jan-12		Roof in good profile. Half barrels in nearly the full profile. Transformer bay only needs a couple more bolts then finished.							
10-Jan-12		Tunnelers working on hanging 11 kV cables all day.							
15-Jan-12		Night shift tunneling crew working on installing floor slabs.							
16-Jan-12		Installed 1x 3m probe hole to release water in roof.							
17-Jan-12	597	Day shift (D/S) had water coming in through drill holes not at high levels, 1hour was taken with water control during D/S, 2 extra roof bolts were installed for support. Night shift drilling out face hit a perched water table. Resulting in flooding of the top portal platform. see photos							

18-Jan-12	597	No movement forward in tunnel today. High pressure at the face out of one 3m drill hole (see photo), water hit at the last 50cm of the drill rod. Night shift drilled out face, at the beginning of drilling the main pressure hole immediately dropped in pressure/quantity. As more holes were installed water pressure started to be relieved. (See photos and video). Rear wheel of Toro changed from slick to d-lug.							
19-Jan-12		No movement forward. Face was fully drilled out last night, water qauntities at lower drainage pipe would be 1-2 seconds to fill up 208L drum. Waiting for water at the face to drop off. Tunneling fully stopped for the day. No Night shift. Discussion about what to do to go forward. Moved 11kV transformer up tunnel using toro. One sheared zone is visible through the face approximately along foliation, thickness >5mm (hard to see due to amount of water coming out of face). Another sheared zone is located approximately 2 meters spacing infront, with similar characteristics. Four joint sets are visible in the face. No evidence of high stress conditions.	0.165	30	15	2	8	0.33	1
20-Jan-12		Water at high quantities, filling 205L bucket at ~2 seconds.							
23-Jan-12		Tunnelers battling with high water flows creating slippery working surfaces and cold conditions to work in. Water has dropped off only a small amount seen in the 205L bucket recording. Matt Tomcyzk has injured foot due to air leg slipping back on floor grate (night shift).							
24-Jan-12		Water still in face (coming out at lower quantities than out by of the face). See Geological long section dated 24/1/12. Rock conditions are the same as last recorded except for Jr where no rock wall contact when sheared is the classification given to the two larger sheared zones at 589m and 596.5m, the spacing between these two sheared zones is greater than 3m therefore the Jr is 2 (i.e +1 due to spacing). Tunnellers currently using wood, mesh and brattice to control the water and keep it off electrics as much as possible. Water on the scale of RMR is >125L/m over a 10m tunnel length, condition of discontinuities would be soft gouge >5mm thick (rating of 0).	0.165	30	15	2	8	0.33	1
26-Jan-12		Water still in face, no more sheared zones seen in face/walls in by of last evaluation and geological long section.							
30-Jan-12		Rock quality at face is good with discussion surrounding moving forward on bolts only and campaining the shotcrete part of the cycle. Water is still "flowing" at rates >125 Litres per minute over the 10 m length from the face (see RMR). Probe holes							

		have been drilled out on ~45° angle (out and up) from the springline to control water away from face for loading.							
31-Jan-12		Jumbo drill is out of action due to damage to boom. Delays associated with water coming out of floor/everywhere while laying floor slabs today. Men working on installing floor panels.							
1-Feb-12		Men working on making boxing on tunnel floor to shotcrete inside of before the panels are layed down. Activity carried out day and night shift. This process has been made to deal with the water as dry mix/ the normal process would get wash out with the amount of water currently coming out of the floor/ draining accross the floor.							
2-Feb-12		Q was evaluated over the <6m of rock exposed at the tunnel face. RQD is "fair", four joint sets are still prominent in the area with one joint set laying at 60 degrees parallel with the tunnel orientation causing a localized area which will need shotcrete before continuing forward. RQD horizontally accross this localised section of approx 2m2 would be less than 10%. Joint alteration was seen to be silty at the most altered with a small clay fraction pressent. Only medium water quantities seen at the face (need to check after drilling out as to the water quantity at the face). No evidence of stress conditions affecting stability present. Men working all day on shotcreting floor panels and placing pre-cast panels ontop, night shift working on getting shotcrete up to date in roof.	1.613333333	55	15	2	3	0.66	1
7-Feb-12		Water coming out of face in centre burn cut (rest of face dry) after round pulled at approximately lunch time. Rock quality looks competent, half barrels seen in full profile. Profile is good all round. Bolting/shotcrete not up-to-date currently.							
8-Feb-12		Power out from 8:45am to 12:00pm due to digger operator shorting power at the s-bend. Department of labour visit at 9:30am, no tunnel inspection due to no power at portal etc.. Down time from 12:00pm till ~2:00pm at lower portal sump, making sure there are no blockages in pipe line, too much water coming out of tunnel for drain to cope with at once, checked settling ponds, no problems there, water still coming out of settling pond tunnel drain at high quantities. Clean water discharging into Just Right Creek. Men working on replacing ventilation bags so they are not creating dirty water etc. (photos from this day are in the log). An incident form was filled out.							
14-Feb-12		Water at face/floor. Rock quality looks good, 2 supplimentary bolts installed at ~630m due to blocky ground. RQD is 50-60%, 4 joint sets visible 126/56 (D/DD) foliation, 286/42 (D/DD). Joint roughness is smooth. Joint alteration is mainly just slightly altered walls, one large sheared zone at 630m, 400mm thick with a clay layer at both sides of 100mm thick, the centre of this zone is shattered rock. Water is still coming out of the face at rates which would make it difficult to lay panels with the normal dry mix method. Once another round is drilled out it will be better to give an estimate of Jw at this point. There is no evidence that stress is affecting the tunnel stability.	0.55	50	15	2	8	0.66	1

		Bolts are the only support in approximately 7m length of ground, ground is competent enough for this amount of support, scalling has been kept up to date. Shotcreting today before another round is drilled out. Shotcrete put in areas of sheared zones to stop the erosion of the walls.							
15-Feb-12		Preparing next section of tunnel for inverts over wet zone.							
16-Feb-12		Men working on boxing and shotcreting panel base over wet zone. Face is dry above ~300mm from floor. Sheared zone at ~638m of ~10mm thickness along foliation. Profile is good. Localised reduction in RQD to ~40%, roof has been bolted up but will need shotcreting before moving ahead another round. One joint set at 48/290 (D/DD) spacing of >300mm repeated several times in face. Noticible variation of foliation with >10 degrees variation over 1m transect parallel with foliation. Foliation away from localised deformation at 56/142 (D/DD). 3 visible joint sets in the face plus randoms.							
21-Feb-12		Still a lot of water coming out of tunnel and onto upper portal slab, this is also bringing with it quantities of loose material which are needing to be cleared by the loader. Men having difficulty in pulling the top right section of the profile, this may have something to do with how the foliation is orientated. Men will need to shotcrete profile before moving forward due to rock mass not being as tidy as previous rounds. Face is dry (no water in floor/roof/face), this may change once face is drilled out again.							
2-Mar-12		Men preparing floor for invert panels. Will have to use process of boxing and shotcreting foundations for inverts due to too much water flowing over floor for dry mix to be effective. Face at 677m, RQD is variable with some sections of >300mm wide <10% RQD. Foliation variable with >15 degrees of difference seen due to localised folding within foliation over the space of 2m. Foliation 48/112 (D/DD) way off the normal orientation, three joint sets plus random are present. Joint surfaces are smooth, with little alteration only really surface oxidation staining. Water is greater than 5L/m at the face and so would have to fit into the medium inflow catagory. No evidence of stress affecting stability of the tunnel.	2.2	40	12	1	1	0.66	1
6-Mar-12		Tunnelling crew worked on shotcreting of floor panels all of weekend. Roof was shotcreted up to date before moving forward as requested on Friday 2nd. Had to re-fire a round from last night during day shift of the 6th.							
7-Mar-12		Grouting team arrived to get started on void infilling beneath panels. Phil and Gordy onsite maintaining road access grading and roller compacting.							
8-Mar-12		Panels installed up to 653m last month. Face very blocky with one main controlling joint set at 48°/280 (D/DD). Spacing between this joint set is >25-30cm, this joint set is approximately perpendicular to foliation and is controling the profile of the roof. Textbook biotite schist with some lenses of compositional layering going on along the foliation, also some sections of high garnet quanities (see photos of rock	3.3	30	6	1	1	0.66	1

		picked up at 670m). Joints are smooth and planar, with surface staing present only. Water at the face is mostly limiting to coming out of the floor up to knee height, quantities would be greater than 5L/min localy over the last round. No stress conditions affecting stability at the face/profile. Men have noted that they have been feeling soft pockets while driling, and loading up due to competency of holes.							
13-Mar-12		Face at 702m, face noticibly more oxidised RQD ~30%, three joint sets visible in the face (last round) plus randoms, smooth joint surfaces, alterted joint walls (lots of oxidation), oxidation visible on joint surfaces and through foliation in some areas making the rock weak. Water at the face coming out of floor in greater quantities than 5L/min. No stress affecting stability of the tunnel profile. The rock quality has deteriated from last week, resulting firing holes not being very competent; hindering loading of holes for blasting. More shotcrete has been installed today below the springline to tidy up an area where small block sizes were fretting out on right rib. No clay zones visible in ribs for last >10m..possibily an indication that we are moving out of the water zone.	1.65	30	12	2	2	0.66	1
14-Mar-12		Rock quality decrease, lots of oxidation at the face and in ribs, only short sections of half barrels seen, RDQ ~30%. Men not able to campaign shotcrete (shotcreting each round).							
15-Mar-12		Face is mostly dry, with very little water coming out of the floor. Rock is quite oxidised both on joint surfaces and through rockmass. Thick clay band along foliation at the face >100mm wide, light whitish grey in colour. Roof an ribs minor fretting vsible. RQD 30% maximum over last round. Profile shape is good. Joint surfaces rough and undulating. Three joint sets plus random. Men not able to campaign shotcrete due to rock not being competent enough in roof.	0.46875	30	12	1.5	8	1	1
21-Mar-12		Face at 715m, ~50 Litres per second coming out of portal, ~20 L/s coming out of face. Water mostly located right at face. Matthew Shore from URS onsite doing evaluation. Face blocky, 4 extra bolts installed at almost right angles to the foliation direction. Three joint sets plus random visible in walls. Foliation at 58/168, J1 at 58+_10/254, and J2 at 52/038. Thick sheared zone <110mm at 714m, light greyish white in color (see photos), orientated along foliation. Some instability along this shear in roof where a hole is seen in shotcrete. Variable across only a few meters of persistence with thickness. Water coming out in the high quantities after the sheared zone from 715m. Explained to Matt the large variation in rock mass that we are experiencing over only short chainage distances (i.e. each round/ 3m).	0.4125	60	12	1	8	0.66	1
26-Mar-12		Tunnel inspection- ~70 Litres per second coming out of portal, build up of finer grained muck at entrance way. Face at 728m, localised folding in ribs has caused low RQD due to cracking in brittle material. Localised folding showing variation in foliation dip of >20 degrees. One joint set at 60-90/245 lots of variation, foliation at ~54/163 D/DD. Water at the face ~30L/second. No stress conditions presenting	1.2375	30	12	1.5	1	0.33	1

		instability at the face. Water coming out of roof, walls (everywhere). Water still coming out of roof >6m from the face, not very nice working conditions, very cold. Men not able to campaign shotcrete due to smaller block sizes.							

B.2 Engineering Geological Scanline Mapping

Date	Distance (m)	Flat Inclination Correction for JointStats	Dip	Dip Direction	Trace Length Above (m)	Trace Length Below	Total Trace Length	Type	End Point Class	Roughness Description	JRC	Joint Aperture (mm)	Infill	Top Termination	Bottom Termination	Jr	Large Scale Planarity (>1m)	Comments
16/06/12	123	123	36	154	0	2	2	Schistosity	Fully Censored	Rough	7	1	Quartz	Shotcrete	Invert	1.5	Planar	Schistosity same direction (multiple bands). 1cm quartz bands within, surface mainly blast damaged so no other outstanding joint sets visible (none present?)
16/06/12	126.5	123.36	46	120	0	2	2	Schistosity	Fully Censored	Smooth	3	0	Clean	Shotcrete	Invert	1	Planar	Rock more weathered, softer. Higher alteration
16/06/12	126.5	123.36																Sample 2
16/06/12	128	124.83	44	124	2	2	4	Schistosity	Fully Censored	Rough	7	20	Quartz			1.5	Planar	Thicker quartz filling on schistosity
16/06/12	131	127.75	45	119	2	2	4	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	Going into man bay, walls blocky, schistosity main joint set.
16/06/12	131.1	127.85	54	76	0	0.5	0.5	Joint	Uncensored	Rough	8	0	Clean	Schistosity	Schistosity	1.5	Planar	New joint cutting perpendicular to schistosity dipping into walls (schistosity dipping into face). Dry

16/06/12	133.5	130.19																Man bay 133.5-139. Milky white precipitate seeping through roof of man bay making 8cm stalactites, 5mm thick (shotcrete cement?)
16/06/12	137	133.60																Mainly only schistosity visible in man bay - Shotcrete covers all though so hard to get measurement
16/06/12	139	135.55																End of man bay - full shotcrete so no measurements
16/06/12	145.5	141.89	48	138	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			2	Undulating	Shotcrete to ground up to this point. Rock moderately weathered, schistosity main foliation, steepening towards 150m
16/06/12	149	145.31	70	76	0.25	1	1.25	Joint	Fully Censored	Rough	8	2	Clay			1.5	Planar	
16/06/12	150	146.28	48	150	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
16/06/12	151	147.26	86	74	0.25	2	2.25	Joint	Fully Censored	Rough	8	2	Clay			1.5	Planar	
16/06/12	152	148.23	40	138	2	3	5	Schistosity	Fully Censored	Smooth	3	0	Clean			2	Undulating	
16/06/12	152.9	149.11	40	135	2	3	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Damp
16/06/12	154	150.18																Rock highly fractured (blasting?) main set = schistosity
16/06/12	155	151.16	35	128	2	3	5	Schistosity	Fully Censored	Smooth	3	2	Clay			1	Planar	Clay filling

16/06/12	157	153.11	48	140	1	2	3	Schistosity	Fully Censored	Smooth	3	2	Quartz	Shotcrete	Invert	1	Planar	157-162m = L rib almost total shotcrete (R rib water supply bay). Quartz filling
16/06/12	160	156.03																Shotcrete to floor on both sides - no measurement and no classifications
16/06/12	164	159.93	80	270	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock with schistosity	Intact rock	1.5	Planar	
16/06/12	164	159.93	50	162	1	2	3	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	
16/06/12	166	161.88	48	118	1	2	3	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	
16/06/12	169	164.81																Schistosity undulating dip 40 near invert and 32 near springline. Rock mass quite intact, only broken along schistosity
16/06/12	170	165.78	43	130	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			2	Undulating	More quartz bands
16/06/12	173	168.71																Rock mostly blast damaged, difficult to see any joint sets or schistosity, shotcrete almost to floor
16/06/12	176	171.64	44	150	2	2	4	Schistosity	Fully Censored	Rough	7	0	Clean			3	Undulating	R rib very lumpy, few 0.5m scale voids
16/06/12	176.5	172.12																Large shear zone (?) visible in L and R rib filled with quartz and biotite bands. Dip of 42, 200mm wide at base, 300mm wide near springline. (Sketch in notebook)
16/06/12	177	172.61	30	150	4	2	6	Shear	Fully Censored	Rough	8	10	Clay			2?	Undulating	Clay band cross cutting schistosity

16/06/12	180	175.54																Schistosity main control, blast damage. RQD low, approaching 0. Slightly weathered. R rib - fault offsetting large quartz infilled segment.
19/06/12	180	175.54	56	156	2	2	4	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	
19/06/12	181	176.51	60	350	2	3	5	Shear	Fully Censored	Rough	8	250	Clay			1.5	Planar	Large clay band cuts perpendicular to schistosity, filling clay and sandy fines plus small (<10mm) angular pebbles. No clear edges, dip and dip direction approximate. Schistosity dip shallower after shear
19/06/12	182	177.49	41	170	0.3	2	2.3	Schistosity	Fully Censored	Rough	7	10	Quartz	Clay band at 181	Invert	1.5	Planar	10-20mm quartz bands, joint spacing decreasing (between schistosity bands)
19/06/12	182.5	177.97	80	350	3	2	5	Shear	Fully Censored	Smooth	4	10	Clay			1	Planar	Thin band of dark grey clay along shear, definate colour change across shear. White crushed quartz/gouge immediately alongside shear. Fault?
19/06/12	184	179.44	60	286	0	0.5	0.5	Joint	Uncensored	Rough	8	0	Clean	Intact rock with schistosity	Ribs	1.5	Planar	
19/06/12	184.5	179.92	75	264	0	1	1	Joint	Uncensored	Smooth	4	0	Clean	Ribs	Shear	1	Planar	Chalky White rock (see sample 3)
19/06/12	187.5	182.85	50	160	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
19/06/12	185	180.41																Sample 3
19/06/12	185.5	180.90	68	150	4	2	6	Shear	Fully Censored	Rough	8	30	Clay			1.5	Planar	Creating a void in roof with weaker material up tunnel of shear band, harder rock down tunnel
19/06/12	188	183.34																Increased weathering, creating voids in R rib to 189m

19/06/12	190	185.29	50	192	1	1.5	2.5	Schistosity	Fully Censored	Rough	7	2	Clay	Intact rock	Intact rock	1.5	Planar	
19/06/12	190.3	185.58	88	232	0	1.5	1.5	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
19/06/12	192.5	187.73	89	49	0.2	1	1.2	Joint	Censored Above	Rough	8	0	Clean		Intact rock	1.5	Planar	
19/06/12	193	188.21	60	260	0	1	1	Joint	Fully Censored	Slightly Rough	6	0	Clean			1.5	Planar	190-193 = large zone in schistosity of 10-20mm quartz bands, high weathering. 193-194.5 = Shotcrete to floor
19/06/12	194.5	189.68																Large quartz bands along schistosity up to 35-40mm thick
19/06/12	195	190.16																Large band 100mm thick, filled with quartz, biotite and moderately weathered
19/06/12	196	191.14	68	288	1	0.5	1.5	Joint	Censored Above	Rough	8	0	Clean		Intact rock	1.5	Planar	
19/06/12	198.5	193.58																Man bay - Shotcrete coming into man bay. Rock more broken, 2 definate joint sets (schistosity and perpendicular joint) plus some shears and other joints. Very wet, weep holes dripping to floor
19/06/12	199	194.07	60	317	0	2	2	Joint	Fully Censored	Smooth	4	1	Clay	Shotcrete	Invert	1	Planar	
19/06/12	199.5	194.55	48	350	3	0.5	3.5	Joint	Censored Above	Smooth	4	0	Clean		Shotcrete	1	Planar	
19/06/12	200	195.04	50	188	0.5	2	2	Schistosity	Fully Censored	Rough	7	2	Clay	Intact rock	Invert	1.5	Planar	

19/06/12	203	197.97																End of man bay. Shotcrete to floor on both sides
19/06/12	205	199.92	46	124	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
19/06/12	206.6	201.48	60	285	6	2	8	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	
19/06/12	214.2	208.89	60	360	1	2	3	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	
19/06/12	220	214.54																To 225m Rock poor, very wet (dripping). Ribs crumbled (blast damaged?), can't get good measurements. 10mm quartz bands, schist dark grey with quartz bands, no clay found. Less shear zones but weaker rock overall. Schistosity continuous, less suplementary joint sets.
19/06/12	221	215.52																Rock highly jointed to 221m. Shotcrete to floor, Schistosity present but more intact, more joint sets visible and all very continuous (but covered so no measurements). RQD lower, can see 3+ joint sets
19/06/12	222	216.49																RQD decreasing (0-10). Rock quite shattered, lots of biotite
19/06/12	226	220.40																Schistosity close together, 10-20mm
19/06/12	233	227.22																Shotcrete to floor still, Voids 220-230 in walls, but not along joint sets. Breaks rough, unweathered etc. Walls still wet.
	246.9	240.78																
	249.7	243.51																

21/06/12	250	243.80	56	110	2	1	3	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Same as above, still wet, shotcrete to floor from 235 onwards. Approaching 250, block size increases, joint spacing increases 100-150mm, less weathering, very wet, still large scale (1-2m) voids (mainly R rib). Perpendicular joint set comes in again. Joints and schistosity are very continuous
21/06/12	253	246.73																Schistosity main foliation, walls rubbly - blast damage? Heavy biotite, schist bands thin
21/06/12	255	248.68																SC to floor
21/06/12	260	253.55																SC to floor - very difficult to see anything, still looks like walls are foliation controlled (schistosity)
21/06/12	265	258.43	58	121	2	1	3	Joint	Fully Censored	Slightly Rough	6	0	Clean			1.5	Planar	Less SC
21/06/12	265	258.43	86	324	0	0.5	0.5	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
21/06/12	266	259.40	44	150	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
21/06/12	267	260.38	48	98	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			2	Undulating	
21/06/12	268.5	261.84	56	20	2	2	4	Joint	Uncensored	Smooth	4	0	Clean	Shotcrete	Shotc rete		Planar	Could mainly only get a D/Dip direction - SC to floor till 285m
21/06/12	270	263.30	58	295	0	1	1	Joint	Uncensored	Smooth	4	1	Clay	Intact rock	Intact rock	1	Planar	
21/06/12	272.5	265.74	70	114	1	2	3	Joint	Fully Censored	Rough	8	2	Clay			1.5	Planar	Weathered biotite/sandy fill

21/06/12	273	266.23	46	190	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
21/06/12	275	268.18	60	136	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
21/06/12	278	271.11	62	298	3	3	6	Joint	Fully Censored	Slightly Rough	6	1	Clay			1.5	Planar	Clay filling
21/06/12	279	272.08	64	196	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
21/06/12	280	273.06	60	192	3	1	4	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	Unweathered
21/06/12	280	273.06	50	298	3	3	6	Joint	Fully Censored	Slightly Rough	6	1	Clay			1.5	Planar	Very prolific joint set 278-280m
21/06/12	285	277.93	24	58	4	3	7	Joint	Fully Censored	Smooth	4	1	Clay			1	Planar	62/147 = Schistosity
21/06/12	287	279.88	60	280	1	4	5	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
21/06/12	289	281.83	55	175	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
21/06/12	289	281.83	50	326	1	2	3	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
21/06/12	290	282.81	60	300	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	3	Undulating	

21/06/12	291.5	284.27	48	150	3	2	5	Schistosity	Fully Censored	Rough	7	2	Clay			1.5	Planar	Clay filling
21/06/12	292	284.76	80	40	1	2	3	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	1.5	Planar	
21/06/12	293.5	286.22	70	26	1	2	3	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	1.5	Planar	Creates void in rib with schistosity
21/06/12	295	287.68	45	45	3	2	5	Joint	Fully Censored	Smooth	4	1	Clay			1	Planar	
21/06/12	295	287.68	44	144	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
21/06/12	296.5	289.15	65	40	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
21/06/12	299.5	292.07	50	295	0	1	1	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
21/06/12	300	292.56	70	135	4	2	6	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	
20/06/12	300	292.56	70	114	3	1	4	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	300-303 - slabby, very wet to dripping. Schist is main foliation
20/06/12	302	294.51																302-310m = muck bay in R rib, L rib heavy shotcrete
20/06/12	303	295.49	84	84	2	2	4	Schistosity	Fully Censored	Rough	7	2	Clay			1.5	Planar	

20/06/12	303.5	295.97																303.5-305 = Very wet - going back to 'slabby' schistosity controlled
20/06/12	304.2	296.66	44	34	0	0.5	0.5	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	
20/06/12	305	297.44	56	176	1	2	3	Joint	Fully Censored	Very Rough	10	0	Clean	Shotcrete, Intact rock?	Invert	3	Undulating	
20/06/12	307.7	300.07	86	270	0	0.5	0.5	Joint	Uncensored	Very Rough	10	2	Clay	Shotcrete	Intact rock	1.5	Planar	
20/06/12	309	301.34	89	90	1	2	3	Joint	Fully Censored	Very Rough	10	2	Clay	Intact rock	Invert	1.5	Planar	
20/06/12	309.3	301.63	72	106	3	1	4	Schistosity	Fully Censored	Very Rough	9	0	Clean			1.5	Planar	
20/06/12	312	304.26	80	338	1	1	2	Joint	Uncensored	Rough	8	1	Clay	Intact rock	Intact rock	3	Undulating	
20/06/12	312	304.26	90	340	2	1	3	Joint	Censored Above	Rough	8	0	Clean	Intact rock	Intact rock	3	Undulating	
20/06/12	312.1	304.36	80	266	1	2	3	Joint	Fully Censored	Rough	8	0	Clean		Invert	1.5	Planar	
20/06/12	312.3	304.56	70	102	2	2	4	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	
20/06/12	313	305.24																313-314 Very broken rock, SC to floor

20/06/12	315	307.19	82	84	0	0.5	0.5	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	3	Undulating	
20/06/12	315.5	307.68	30	13	2	2	4	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
20/06/12	316	308.16	55	124	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
20/06/12	317	309.14	70	106	3	1.5	4.5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	317-322 Man bay, both ribs heavy shotcrete
20/06/12	320	312.06	68	112	3	1	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
20/06/12	321	313.04																Half barrels in R rib
20/06/12	322	314.01																322-332 Shotcrete to floor in L rib
20/06/12	322.7	314.70	48	138	0.5	1.5	1.5	Schistosity	Fully Censored	Smooth	3	0	Clean	Shotcrete	Invert	1	Planar	
20/06/12	323	314.99																Sample 5
20/06/12	324	315.97																Large (2m tall, 0.6m into rib) void, schistosity controlled
20/06/12	325	316.94	52	124	3	1	4	Schistosity	Fully Censored	Slightly Rough	5	1	Clay			1.5	Planar	Rock more crumbled - dark schist and quartz bands, areas very broken

20/06/12	326	317.92	52	284	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
20/06/12	326.2	318.11	54	102	3	1	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
20/06/12	327	318.89	70	24	2	2	4	Joint	Fully Censored	Very Rough	10	0	Clean			1.5	Planar	
20/06/12	328	319.87	70	42	0	2	2	Joint	Uncensored	Rough	8	0	Clean	Intact rock		3	Undulating	
20/06/12	330	321.82	89	88	0	1.5	1.5	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
20/06/12	332.4	324.16	40	230	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	
20/06/12	332.4	324.16	78	210	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	
20/06/12	333	324.74																Down to 335, rock more blocky, 3+ joint sets. Roof has large voids
20/06/12	333.6	325.33	63	39	0.7	2	2.7	Joint	Censored Below	Rough	8	1	Quartz	Intact rock		3	Undulating	
20/06/12	334	325.72	50	120	3	2	5	Schistosity	Fully Censored	Smooth	3	2	Quartz			1	Planar	Hard quartz fill, unweathered
20/06/12	334	325.72	89	4	0.5	2	2.5	Joint	Censored Below	Very Rough	10	0	Clean	Intact rock		1.5	Planar	

20/06/12	335	326.69	42	136	2	2	4	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	
20/06/12	335.5	327.18	60	132	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
20/06/12	335.7	327.37	60	2	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	Mainly schistosity controlled, other joint sets coming in
20/06/12	339	330.59																Shotcrete to floor, block size decreases, broken on blast damage not joints. Still schistosity main control
20/06/12	339.5	331.08	90	62	0.5	1	1.5	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	
20/06/12	340	331.57	38	156	3	1	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
20/06/12	340	331.57	60	90	2	1	3	Joint	Censored Above	Very Rough	10	2	Quartz	Intact rock	Intact rock		Planar	
20/06/12	341	332.54																Wall broken along tunnel parallel joint (see below)
20/06/12	342	333.52	60	50	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	Well broken along tunnel parallel joint - lots of crumbled rock at invert, void into wall (joint sloping into L rib)
20/06/12	343	334.49																343-344 transformer bay
20/06/12	345	336.44	56	120	2	1	3	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	342-345 shotcrete to floor, transformer bay in L rib. Increased quartz and dark biotite bands

20/06/12	346.6	338.00	56	120	2	1	3	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	Large 20-30mm quartz band see photo 0406. Schistosity controlled from 345m.
20/06/12	349.5	340.83	40	128	3	1	4	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	344-350m bay in R rib - full shotcrete
20/06/12	350	341.32	58	225	1	2	3	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	1.5	Planar	Half barrels at 48m
14/06/12	350	341.32	48	223	2	2	4	Joint	Fully Censored	Slightly Rough	6	0	Clean			3	Undulating	
14/06/12	350.1	341.42	46	120	0.3	0.7	1	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	
14/06/12	353.7	344.93	82	216	0.2	2	2.2	Joint	Fully Censored	Slightly Rough	6	0	Clean	Shotcrete	Invert	1.5	Planar	
14/06/12	354.5	345.71	64	158	0.2	2	2.2	Joint	Fully Censored	Slightly Rough	6	0	Clean	Shotcrete	Invert	1.5	Planar	
14/06/12	355	346.20	80	216	2	2	4	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	
14/06/12	355.2	346.39	60	120	1	2	3	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	
14/06/12	357.3	348.44	58	298	2	2	4	Joint	Fully Censored	Slightly Rough	6	2	Clay			1.5	Planar	
14/06/12	357.8	348.93	55	320	0.4	2	2.4	Joint	Censored Below	Slightly Rough	6	2	Clay	Intact rock		1.5	Planar	

14/06/12	357.8	348.93	60	50	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
14/06/12	357.9	349.02	44	160	0	2	2	Joint	Fully Censored	Rough	8	0	Clean	Shotcrete	Invert	1.5	Planar	
14/06/12	358	349.12	68	42	3	2	5	Joint	Fully Censored	Smooth	4	2	Clay			1	Planar	Higher Weathering
14/06/12	360	351.07	42	130	2	1	3	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Weathering increases, schistosity truncated by tunnel-axis-parallel joint
14/06/12	360.3	351.36	50	290	3	2	5	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	RQD drop, more fractured - blasting?
14/06/12	360.6	351.66	60	32	0.4	2	2.4	Joint	Fully Censored	Smooth	4	0	Clean	Shotcrete, Intact rock?	Invert	1	Planar	
14/06/12	362.5	353.51	56	12	0	1	1	Joint	Uncensored	Slightly Rough	6	0	Clean	Intact rock	Intact rock	1.5	Planar	
14/06/12	363	354.00	64	132	1	0	1	Schistosity	Fully Censored	Slightly Rough	5	2	Clay		Against joint at 362.5	3	Undulating	
14/06/12	364	354.97	58	110	0.1	1.5	1.6	Joint	Uncensored	Rough	8	0	Clean	Schistosity	Intact rock	1.5	Planar	Wet, heavily jointed
14/06/12	365	355.95	70	38	0	1	1	Joint	Fully Censored	Slightly Rough	6	2	Clay	Jointed Rock	Intact rock	1.5	Planar	
20/06/12	366	356.92																Very blocky, schistosity main joint set. Weathering and block size increase 365-370.

20/06/12	367.5	358.39	70	22	1	2	3	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	Damp
20/06/12	368	358.87	38	296	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	Wet
20/06/12	368	358.87	52	138	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			2	Undulating	Dry
20/06/12	368.1	358.97	40	298	2	1	3	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	Wet
20/06/12	369	359.85	55	126	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Dry
20/06/12	369.5	360.34	56	120	3	1	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
20/06/12	370	360.82																Man bay to 381m. Schistosity flattening a bit at 381. Shotcrete to floor and in R rib to 400m. Rocks slight to moderately weathered. Less blocky, schistosity main control. Roof very slabby (lots of extra rock bolts in man bay), schistosity undulating (dip 50 near springline, 20 near floor). Roof has ridges from well indurated schistosity bands
20/06/12	373.7	364.43	50	140	2	2	4	Schistosity	Fully Censored	Smooth	3	2	Clay			1	Planar	Sandy clayey fill
20/06/12	374.8	365.51	48	140	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
20/06/12	374.8	365.51	45	27	1	2	3	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	
20/06/12	375	365.70	50	136	2	1	3	Schistosity	Fully Censored	Smooth	3	2	Clay			1	Planar	

20/06/12	375	365.70	50	314	0	1	1	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
20/06/12	386.5	376.92																Large void in L rib
20/06/12	397	387.15																Rock less slabby to 397. More fractured (blast damaged (?)) not breaking along fractures. Walls and roof rough rather than ridged (as in man bay). Schistosity main joint set
20/06/12	397.7	387.84	52	138	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
20/06/12	400	390.08	58	90	2	1	3	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	Rock fractured again
2/07/12	400	390.08																Rock stronger, less fractured/blast damaged, 2 joint sets (see 404 & 405) main control in ribs
2/07/12	402	392.03	37	300	1	3	4	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	Schistosity dominant, rock wet and more weathered
2/07/12	404	393.98	50	148	2	3	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Rock blast damaged, quartz bands bigger, 10mm
2/07/12	405	394.96	35	32	0	0.5	0.5	Joint	Uncensored	Slightly Rough	6	0	Clean	Intact rock	Intact rock	1.5	Planar	Rock very homogeneous, only thin quartz bands
2/07/12	405	394.96	62	164	2	3	5	Schistosity	Fully Censored	Very Smooth	1	0	Clean			1	Planar	
2/07/12	405.5	395.44	60	141	2	2	4	Schistosity	Fully Censored	Slightly Rough	5	1	Clay			1.5	Planar	Clay fill

2/07/12	406.5	396.42	80	244	0.5	2	2.5	Joint	Censored Below	Rough	8	0	Clean	Intact rock		3	Undulating	Joint controlling walls/overbreak
2/07/12	408	397.88	56	132	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
2/07/12	409	398.86																Walls schist controlled but at spacing of ~150mm
2/07/12	410	399.83	70	242	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
2/07/12	410	399.83	48	158	3	2	5	Schistosity	Fully Censored	Smooth	3	0.5	Clay			1	Planar	Transformer in L rib - use R rib
2/07/12	411	400.81	40	264	0.5	2	2.5	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
2/07/12	412	401.78	45	172	2	2	4	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	Rock wet -> dripping
2/07/12	414	403.73																Still very broken, schistosity controlled
2/07/12	415	404.71	54	150	2	2	4	Schistosity	Fully Censored	Rough	7	1	Sandy			1.5	Planar	415-418 very damaged in L rib. SC to floor
2/07/12	418	407.63	48	128	2	2	4	Schistosity	Fully Censored	Rough	7	1	Sandy			1.5	Planar	Sandy fill. R rib relatively homogeneous rock, schistosity controlled
2/07/12	419	408.61																Blast damage - rock very rubbly, SC to floor

2/07/12	420	409.58	80	56	0	2	2	Joint	Fully Censored	Rough	8	0	Clean			3	Undulating	
2/07/12	421	410.56	60	164	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
2/07/12	422	411.53	82	83	1	2	3	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	1.5	Planar	Large (2m) void in L & R rib, SC to floor
2/07/12	423.4	412.90	58	141	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
2/07/12	423.4	412.90	50	88	0	1	1	Joint	Uncensored	Slightly Rough	6	0	Clean	Intact rock	Intact rock	1.5	Planar	
2/07/12	424.5	413.97	60	260	0	2	2	Joint	Censored Below	Smooth	4	0	Clean	Intact rock		2	Undulating	
2/07/12	425	414.46	68	90	3	2	5	Joint	Fully Censored	Smooth	4	0	Clean	Intact rock	Invert	2	Undulating	
2/07/12	425.4	414.85	54	116	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
2/07/12	425.5	414.95	60	264	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
2/07/12	426	415.44	45	318	0	3	3	Joint	Censored Below	Rough	8	0	Clean	Intact rock		3	Undulating	Blocky/blast damage
2/07/12	427	416.41	45	288	0	3	3	Joint	Censored Below	Rough	8	0	Clean	Intact rock		3	Undulating	Surface moderately weathered

2/07/12	427.7	417.09	70	150														Change in schistosity dip down tunnel
2/07/12	428.7	418.07	40	110	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			2	Undulating	
2/07/12	428	417.39																Void in R rib, blocky, shattered rock in L rib. Schistosity very prominent, undulating. 1/2 barrels below springline
2/07/12	429	418.36	30	296	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
2/07/12	429	418.36	54	310	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	Void controlled by below 2 joint sets in R rib (SC to floor)
2/07/12	431	420.31																Void as above, in R rib (SC to floor)
2/07/12	432	421.29	82	50	1	2	3	Joint	Fully Censored	Smooth	4	0	Clean	Intact rock	Invert	1	Planar	SC to floor in R rib
2/07/12	432.7	421.97	56	160	2	2	4	Schistosity	Fully Censored	Smooth	3	0.5	Clay			1	Planar	
2/07/12	433.5	422.75	42	6	1	3	4	Joint	Fully Censored	Rough	8	0	Clean			3	Undulating	
2/07/12	433.6	422.85	80	270	0	2	2	Joint	Censored Below	Smooth	4	1	Clay	Intact rock		1	Planar	
2/07/12	435	424.21	56	138	3	2	5	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	

2/07/12	436	425.19	50	254	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	3	Undulating	R rib wet -> dripping. Rock very broken - no neat joint surfaces. SC to floor, horizontal joint set but no clear measurement
2/07/12	437	426.16																Void in R rib -> 440m, SC to floor
2/07/12	437.5	426.65	84	250	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	3	Undulating	
2/07/12	438.7	427.82	80	13	0	2	2	Joint	Censored Below	Slightly Rough	6	0	Clean	Intact rock		1.5	Planar	
2/07/12	439.2	428.31	40	130	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
2/07/12	440	429.09	44	154	0.5	2	2.5	Schistosity	Fully Censored	Smooth	3	0	Clean	Intact rock/Shotcrete	Invert	1	Planar	
2/07/12	441	430.06																441-443 - band of increased weathering - moderate. Schistosity still main joint set.
	442.5	431.53	68	298	1	3	4	Joint	Fully Censored	Smooth	4	1	Clay	Intact rock	Invert	1	Planar	
2/07/12	442.7	431.72	62	291	1	3	4	Joint	Fully Censored	Smooth	4	1	Clay	Intact rock	Invert	1	Planar	
2/07/12	442.7	431.72	70	110	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
2/07/12	443.5	432.50	40	112	3	1	4	Shear	Censored Above	Rough	8	20	Clay	Roof		1.5	Planar	Shear - not visible in R rib, goes to roof and stops (creating void in L rib and roof). Some clay/softer fill but mainly just more sheared rock. Zone 200mm thick, same orientation as schistosity.

2/07/12	445	433.96	42	144	3	1	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
2/07/12	445.5	434.45																445.5-449.3 - Man bay in L rib, full SC to floor down to 450
2/07/12	447	435.91	70	260	1	2	3	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
2/07/12	449	437.87	46	164	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Man bay - full SC, seems to mainly be schistosity controlled
4/07/12	458	446.64																Full SC in both ribs coming into man bay, SC to floor in R rib to 465m. Large void just before man bay at 450m.
4/07/12	459	447.62	47	145	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
4/07/12	460	448.59	50	140	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Start of intense orange precipitate coating on ribs. Rock itself Slightly to moderately weathered
4/07/12	461	449.57	88	240	1	3	4	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	3	Undulating	
4/07/12	461.5	450.06	50	304	0	2	2	Joint	Censored Below	Smooth	4	0	Clean	Intact rock		1	Planar	
4/07/12	462	450.54																Orange precipitate coats everything. Schistosity main control on ribs
4/07/12	463	451.52																To 465m, orange coat decreases in L rib, R rib highly orange beneath SC (0.5m from invert up).

4/07/12	463.5	452.01	80	80	1	2	3	Joint	Fully Censored	Smooth	4	0	Clean	Intact rock	Invert	1	Planar	
4/07/12	464	452.49	45	150	4	2	6	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	Schistosity main control
4/07/12	465	453.47	56	332	1	2	3	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	1.5	Planar	
4/07/12	466.2	454.64	53	320	0	1	1	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
4/07/12	467	455.42	40	178	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
4/07/12	467	455.42	70	58	0	3	3	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
4/07/12	468	456.39	40	162	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Rock in both ribs very amorphous (blast damaged?) - not breaking along joints or schistosity. Both sides still orange
4/07/12	470	458.34	88	56	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	
4/07/12	471	459.32																L rib amorphous orange mass of rock, no schistosity or joints visible. R rib - schistosity visible but no clean surfaces. Both ribs orange. Rock bolts rusting like crazy.
4/07/12	473	461.27																Rock highly 'rubbly', weathered, no clear joint surfaces.
4/07/12	475	463.22	42	160	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Coated with highly weathered precipitate but actual rockmass only slightly weathered

4/07/12	477.5	465.66																Large void in L rib. Rock deteriorated - still very rubbly. Zone 0.3-0.5m wide, weathering decreases, void continues up into roof but not visible in R rib. R rib very finely banded, only breaking along schistosity.
4/07/12	479.5	467.61	52	130	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	R rib a lot less weathered, just dripping, not flowing. SC further down in R rib, blast damage more intense, L rib seems only schistosity controlled + maybe one other set.
4/07/12	480	468.10	50	112	3	2	5	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	Orange precipitate formed over surface of rock, water coming along joints and through boreholes. Orange coats all - difficult to tell aperture, roughness etc.
4/07/12	481	469.07	50	136	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Joint spacing/block size increasing
4/07/12	482	470.05	55	134	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
4/07/12	483	471.02	70	58	3	2	5	Joint	Fully Censored	Rough	8	0	Clean			3	Undulating	Rock more weathered and quite blocky. R rib SC down lower, more blast damage.
4/07/12	484	472.00	50	142	3	2	5	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	SC to floor to 486m
4/07/12	484.5	472.48	60	260	0	0.5	0.5	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
4/07/12	485	472.97	55	164	3	2	5	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	
4/07/12	486	473.95																Highly weathered in L rib, SC to floor
4/07/12	486.3	474.24																SC to floor until 490m. Ribs mainly schistosity controlled.

4/07/12	489	476.87																R rib highly weathered 489-490m. Weathered along schistosity, but mainly just surficial weathering (precipitate). Weathering from end of SC to invert.
4/07/12	490	477.85	57	130	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
4/07/12	491	478.82																Highly blast damaged L & R rib. Schistosity (as above) main control, also scanline parallel joint set visible but covered by SC. SC almost to floor, increased water and greenish weathering.
4/07/12	492	479.80	62	145	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
4/07/12	492	479.80	55	8	0	0.5	0.5	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	3	Undulating	Quite blast damaged, mainly schistosity controlled, but some other joints. Weathering and water increasing.
4/07/12	492.6	480.38	52	110	3	2	5	Joint	Fully Censored	Smooth	4	1	Clay			1	Planar	
4/07/12	493.2	480.97	65	222	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
4/07/12	494	481.75	63	152	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
4/07/12	495	482.72	60	145	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Increased weathering of qtz bands in schist
4/07/12	495	482.72	38	2	2	0	2	Joint	Censored Above	Rough	8	0	Clean		Intact rock	1.5	Planar	
4/07/12	496	483.70	44	142	3	2	5	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	Very wet -> dripping

4/07/12	496.5	484.19	85	56	1	2	3	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	1.5	Planar	Joint controlling ribs, large void in R rib. Qtz bands 'zig-zag' folded within schist
4/07/12	497.7	485.36	72	80	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
4/07/12	497.7	485.36	72	235	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock/Schistosity		1.5	Planar	
4/07/12	498.5	486.14	64	62	0	2	2	Joint	Censored Below	Smooth	4	0	Clean	Intact rock		1	Planar	
4/07/12	498.5	486.14	57	252	0	1	1	Joint	Uncensored	Slightly Rough	6	0	Clean	Intact rock	Intact rock	1.5	Planar	
4/07/12	499	486.63																1/2 barrels
4/07/12	500	487.60	34	284	2	2	4	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	
4/07/12	500	487.60	66	147	3	2	5	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	500-506m Walls blast damaged and rubbly
5/07/12	500	487.60	35	280	0	1	1	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
5/07/12	500.5	488.09	58	134	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	501	488.58	88	36	0	1	1	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	

5/07/12	502	489.55	50	130	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	502.5	490.04	30	288	0	1	1	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
5/07/12	502.5	490.04	82	42	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
5/07/12	503	490.53	62	162	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
5/07/12	503	490.53	56	122	2	2	4	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	
5/07/12	505	492.48	50	295	0	2	2	Joint	Censored Below	Rough	8	1	Clay	Intact rock		1.5	Planar	
5/07/12	505	492.48	60	140	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	506	493.45	50	135	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	507	494.43	50	308	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
5/07/12	509	496.38	58	152	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	510	497.35	50	138	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	

5/07/12	510	497.35	70	55	3	1	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	510-512m, 1/2 barrels in R rib, very smooth walls, L rib more blocky.
5/07/12	512	499.30																512-516.5m man bay in L rib. Half barrels across from bay in R rib, but also one round unblasted.
5/07/12	512.5	499.79	48	308	0	2	2	Joint	Censored Below	Slightly Rough	6	0	Clean			3	Undulating	
5/07/12	514	501.25	30	140	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	515	502.23	58	130	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	516	503.20	56	132	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	517	504.18	55	130	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	518	505.15																Sample 7 (larger)
5/07/12	519.5	506.62	56	136	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Man bay. Jt spacing decreased, 100mm blocks, walls very blocky, R rib full of SC.
5/07/12	520	507.10	35	320	1	2	3	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
5/07/12	520	507.10	55	142	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	

5/07/12	521	508.08	60	325	0	1	1	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	2	Undulating	
5/07/12	521.5	508.57	80	48	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	3	Undulating	
5/07/12	521.5	508.57	56	144	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	522	509.05	60	286	1	4	5	Joint	Fully Censored	Smooth	4	0	Clean	Intact rock	Invert	2	Undulating	
5/07/12	523	510.03	48	152	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	524	511.01	70	264	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
5/07/12	524	511.01	34	140	4	2	6	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	
5/07/12	524.5	511.49	36	144	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	524.5	511.49	60	268	0	3	3	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	Sample 6
5/07/12	525	511.98	58	156	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			2	Undulating	Mod-High weathered
5/07/12	526.5	513.44	70	278	0	2	2	Joint	Censored Below	Rough	8	1	Clay	Intact rock		1.5	Planar	Clay fill

5/07/12	527.5	514.42	50	160	3	3	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	528	514.91	58	260	1	3	4	Joint	Fully Censored	Rough	8	0.2	Clay			1.5	Planar	Weathered fill
5/07/12	529.4	516.27	58	150	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	530	516.86	70	230	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Joint set below		1.5	Planar	
5/07/12	530	516.86	46	4	0.5	3	3.5	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	1.5	Planar	
5/07/12	530	516.86	58	85	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	Large void L rib - into wall 1m, empty, under another overhanging block so not SC. Overhang SC though. Along schistosity and rib-parallel joint set.
5/07/12	530	516.86	60	266	1	2	3	Joint	Fully Censored	Rough	8	0.5	Sandy	Intact rock	Invert	3	Undulating	R rib smooth to 532m but void at springline. Sandy fill.
5/07/12	530.3	517.15	55	140	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	530.5	517.34	60	153	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	530.5	517.34	46	12	0.5	2	2.5	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
5/07/12	531.1	517.93	54	324	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	

5/07/12	531.2	518.03	74	265	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	3	Undulating	
5/07/12	532	518.81	32	28	1	2	3	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	1.5	Planar	
5/07/12	532.5	519.29	60	140	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	533.5	520.27	60	138	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	534	520.76	54	293	3	3	6	Joint	Fully Censored	Rough	8	0	Clean			3	Undulating	
5/07/12	536	522.71																Start of SC to floor in both ribs (muck bay in R rib 536-545.5m). Till 547m in L rib, 550m in R rib. Tunnel ribs blocky, mainly schistosity controlled, no 1/2 barrels but less blast damage.
5/07/12	537.1	523.78	62	158	4	2	6	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	Schist well banded
5/07/12	547.3	533.73	58	140	4	2	6	Schistosity	Fully Censored	Rough	7	0	Clean			3	Undulating	
5/07/12	548	534.41	64	165	4	2	6	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	
5/07/12	548.3	534.70	60	132	4	2	6	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	
5/07/12	548.5	534.90	70	243	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	

5/07/12	549	535.39	74	224	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		3	Undulating	
5/07/12	550	536.36	56	133	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	551	537.34	58	150	3	3	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	552.5	538.80	50	276	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
5/07/12	554.5	540.75	60	132	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	555	541.24	55	137	0	3	3	Joint	Censored Below	Rough	8	0	Clean	Intact rock		3	Undulating	
5/07/12	555	541.24	70	305	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		3	Undulating	
5/07/12	556	542.21	58	136	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	SC to floor both ribs
5/07/12	556	542.21	70	244	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	
5/07/12	557	543.19	66	236	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	
5/07/12	558	544.16	58	130	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	

5/07/12	559	545.14																559-568m Transformer bay. SC increasing to 575m. No access to L rib but looks mainly schistosity controlled
5/07/12	560	546.11	60	240	0	1	1	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
5/07/12	563	549.04	75	65	0.5	2	2.5	Joint	Fully Censored	Rough	8	0	Clean			3	Undulating	
5/07/12	563	549.04	55	317	0	3	3	Joint	Censored Below	Slightly Rough	6	0	Clean	Intact rock		3	Undulating	
5/07/12	564	550.01	48	128	4	2	6	Schistosity	Fully Censored	Smooth	3	0.2	Clay			1	Planar	Weathered surface, slight clay fill
5/07/12	564	550.01	86	212	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
5/07/12	565	550.99	45	324	0	3	3	Joint	Censored Below	Slightly Rough	6	0	Clean	Intact rock		3	Undulating	
5/07/12	566.5	552.45	40	146	3	3	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	568	553.91																R rib rubbly, no clear joint sets
5/07/12	569	554.89	50	146	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	570	555.86	52	138	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	

5/07/12	570	555.86	55	90	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	571	556.84	50	134	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	572.5	558.30	50	280	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
5/07/12	573	558.79	50	135	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Not much measureable
5/07/12	574	559.77	50	136	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	574	559.77	70	300	0	1	1	Joint	Censored Above	Rough	8	0	Clean	Shotcrete	Intact rock	1.5	Planar	Continuous every 0.5m for 3m
5/07/12	574	559.77	52	120	3	3	6	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	Shiny greenish coating on joint surface (biotite decayed to chlorite?)
5/07/12	575	560.74	50	118	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Rock becoming rubblier down tunnel but more SC.
5/07/12	575	560.74	58	106	3	3	6	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	
5/07/12	577	562.69	50	292	4	3	7	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	
5/07/12	578	563.67	75	36	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	

5/07/12	578	563.67	65	166	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	580	565.62	80	276	3	0	3	Joint	Censored Above	Rough	8	0	Clean		Intact rock	1.5	Planar	Quite well shotcreted so most surfaces obscured
5/07/12	581	566.59	55	130	0	2	2	Joint	Censored Below	Rough	8	1	Clay	Intact rock		3	Undulating	Greenish clay fill
5/07/12	582	567.57	52	235	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		3	Undulating	
5/07/12	582	567.57	57	124	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		3	Undulating	
5/07/12	583.5	569.03	42	280	4	4	8	Joint	Fully Censored	Slightly Rough	6	1	Clay			1.5	Planar	Hard fill. Biotite very weathered.
5/07/12	585	570.49	55	159	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	100mm clay/shear band along schistosity. Bluey silvery clay with shards of qtz within. Clay bands 10mm thick.
5/07/12	586	571.47	50	158	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Walls roughly broken not along clear joint sets. SC to floor still.
5/07/12	586.5	571.96	62	160	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	587	572.44	55	230	0	2	2	Joint	Censored Below	Smooth	4	0	Clean	Intact rock		1	Planar	
5/07/12	588	573.42	60	148	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	

5/07/12	588	573.42	80	64	0	3	3	Joint	Censored Below	Slightly Rough	6	0	Clean	Intact rock		1.5	Planar	
5/07/12	589	574.39	60	118	4	2	6	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	Void L rib on schistosity and this joint
5/07/12	589.5	574.88	65	270	0	1	1	Joint	Censored Above	Rough	8	0	Clean	Shotcrete	Intact rock	1.5	Planar	
5/07/12	590	575.37	65	152	4	2	6	Schistosity	Fully Censored	Smooth	3	1	Clay			1	Planar	
5/07/12	590	575.37	70	86	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
5/07/12	591	576.34	40	276	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	591-595 Walls very flat along below joint set, smooth and less voids. This joint set forming the top of the voids with schistosity.
5/07/12	591.5	576.83	70	90	4	2	6	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
5/07/12	592	577.32	56	115	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	593	578.29	56	136	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	594	579.27	56	138	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	594	579.27	70	48	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			3	Undulating	Controlling rib orientation

5/07/12	595	580.24	88	38	1	2	3	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	1.5	Planar	495-450m very wet, roof dripping, SC to floor.
5/07/12	595.5	580.73	63	160	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	595.5	580.73	70	104	0.25	1.3	1.55	Joint	Censored Above	Smooth	4	0	Clean	Intact rock/Shotcrete	Intact rock	1	Planar	
5/07/12	596	581.22	36	298	0.3	1.2	1.5	Joint	Censored Above	Slightly Rough	6	0	Clean	Intact rock/Shotcrete	Intact rock	3	Undulating	
5/07/12	597	582.19	65	77	0	2	2	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
5/07/12	597	582.19	65	122	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Schistosity plus joint (see below) forming wedge voids
5/07/12	597	582.19	55	90	0	2	2	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
5/07/12	598	583.17	38	288	0	1.5	1.5	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	
5/07/12	598	583.17	80	50	0	1.5	1.5	Joint	Uncensored	Slightly Rough	6	0	Clean	Intact rock	Intact rock	1.5	Planar	
5/07/12	598	583.17	65	156	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
5/07/12	600	585.12																L rib void, no visible joints (SC), S. weathered, less water to R of vent bag. Flowing. Full SC to floor till 602m.

10/07/12	602	587.07																602-603m Rock very broken as at 605.5-607m Only schistosity visible
10/07/12	602.5	587.56																602.5-608.5m Mesh and plastic in roof and down to springline, wood board above vent bag too. Elephant trunks, lots of water sheeting off plastic.
10/07/12	603.8	588.83	64	84	2	2	4	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	
10/07/12	604.6	589.61																LARGE (50mm) clay band, blueish grey clay, continuous into roof and R rib. Along schistosity. Incr in large (10mm) qtz veins either side.
10/07/12	605	590.00	65	150	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
10/07/12	605	590.00	70	200	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	Random joint set
10/07/12	605	590.00	80	74	2	2	4	Joint	Fully Censored	Slickensided	0	5	Clay			0.5	Planar	605.5-607m Rock very broken, spacing <60mm (20-30mm). Clay bands 5mm within schistosity
10/07/12	607	591.95	70	68	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			3	Undulating	
10/07/12	608.5	593.41	40	270	1	2	3	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	1.5	Planar	608.5-610.5m No SC in roof, drain holes and elephant trunks, mesh and plastic bolted to roof to keep water off vent bag.
10/07/12	608.5	593.41	84	38	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			3	Undulating	
10/07/12	608.6	593.51																Shear on schistosity (see below), blueish grey clay fill with crushed quartz. 10mm ap, very broken and weathered zone up tunnel of it, 80mm zone in total

10/07/12	609	593.90	66	156	3	2	5	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	
10/07/12	610	594.87	60	158	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
10/07/12	610	594.87	60	275	3	2	5	Joint	Fully Censored	Smooth	4	0	Clean			2	Undulating	
10/07/12	611.5	596.34	64	270	3	2	5	Joint	Fully Censored	Smooth	4	0	Clean			2	Undulating	Forming roof
10/07/12	611.5	596.34	58	148	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Voids in both walls. Sample 1
10/07/12	613	597.80																Schist as above, walls quite intact, large block sticking out into ribs but total SC to floor
10/07/12	614	598.77	58	138	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
10/07/12	615	599.75																No clear joint sets, SC to floor in L rib
10/07/12	616	600.72	62	155	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
10/07/12	617	601.70	44	298	0	1	1	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	Walls don't have distinct sets - R rib: horiz jt coming in but above jt (618.5m) it is less pronounced
10/07/12	618.5	603.16	80	50	0	2	2	Joint	Censored Below	Smooth	4	0	Clean	Intact rock		1	Planar	

10/07/12	620	604.62	64	144	3	2	5	Schistosity	Fully Censored	Smooth	3	0.2	Clay			1	Planar	R rib up to man bay very blocky, few clear joint sets.
10/07/12	621	605.60	55	128	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	621-628m Man bay - full of mesh and plastic, so no view of L rib. SC to floor till 649
10/07/12	622	606.57	85	250	1	2	3	Joint	Fully Censored	Slightly Rough	6	0	Clean	Intact rock	Invert	1.5	Planar	
10/07/12	624	608.53	60	150	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
10/07/12	625	609.50	90	57	0.5	1.5	2	Joint	Censored Below	Slickensided	0	0	Clean	Intact rock		0.5	Planar	Forming rib orientation. Continuous as rib for 3m
10/07/12	626	610.48	60	150	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
10/07/12	627	611.45	75	62	0.5	1.5	2	Joint	Censored Below	Slickensided	0	0	Clean	Intact rock		0.5	Planar	
10/07/12	629.3	613.69	58	135	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
10/07/12	630	614.38	80	66	0.5	2	2.5	Joint	Fully Censored	Smooth	4	0	Clean	Intact rock	Invert	1	Planar	
10/07/12	630	614.38	60	134	3	2	5	Schistosity	Fully Censored	Smooth	3	1.5	Clay			1	Planar	Brown weathered clay fill (alters 1cm out joint sides)
10/07/12	632	616.33	25	264	0	3	3	Joint	Fully Censored	Smooth	4	1	Clay			2	Undulating	

10/07/12	632	616.33	60	146	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
10/07/12	634	618.28	60	167	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
10/07/12	635	619.25	40	285	2	2	4	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	Large void L rib
10/07/12	636.5	620.72	50	284	2	2	4	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	Joint running parallel to scanline, goes for at least 4m. Joint very continuous, 0.5m spacing up R rib
10/07/12	636.7	620.91	58	156	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Strong schistosity showing through SC, looks like some blocks may fall out but actually don't move, shotcreted in. Open joints but prob from blasting.
10/07/12	641.4	625.49	55	142	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Void at 40 in L rib (covered in SC)
10/07/12	645	629.00	45	282	2	2	4	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	Joint running parallel to scanline, goes for at least 4m.
10/07/12	646.2	630.17	54	152	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
10/07/12	649	632.91	50	130	3	2	5	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	SC to floor both sides since man bay, difficult to get clear reading
10/07/12	649.5	633.39	46	287	0	3	3	Joint	Censored Below	Smooth	4	0	Clean	Intact rock		1	Planar	
10/07/12	650	633.88	54	140	3	2	5	Schistosity	Fully Censored	Smooth	3	0.5	Clay			1	Planar	SC to floor both ribs

11/07/12	650	633.88	52	144	3	2	5	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	
11/07/12	654	637.78																Very broken, void in L rib but full of SC.
12/07/12	655	638.76	54	128	3	2	5	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	
12/07/12	655	638.76	48	290	2	2	4	Joint	Fully Censored	Slightly Rough	6	0	Clean			3	Undulating	SC to floor till 665
12/07/12	657	640.71	60	138	3	2	5	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	
12/07/12	657.5	641.19	50	290	2	2	4	Joint	Fully Censored	Slightly Rough	6	0	Clean			3	Undulating	
12/07/12	658	641.68	80	220	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			3	Undulating	Parallel to ribs
12/07/12	659	642.66	58	140	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
12/07/12	660.5	644.12	54	288	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			3	Undulating	
12/07/12	661	644.61																661-663m R wall relatively broken, but 1/2 barrels. No clean jt sets. Schist dark, only thin qtz bands.
12/07/12	664	647.53																664-667m Qtz bands incr in frequency, rock very stripey. Very thin bands, rock more broken, not cleanly along schistosity.

12/07/12	666	649.48	58	128	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
12/07/12	667	650.46	56	128	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
12/07/12	668	651.43																Void in R rib - full SC till 669m
12/07/12	668.4	651.82	58	156	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
12/07/12	670	653.38	70	65	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		3	Undulating	Rock slabby, relatively intact. 670-671 rock becomes more broken, schistosity dominant.
12/07/12	671	654.36	56	196	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
12/07/12	671	654.36	35	296	1	3	4	Joint	Fully Censored	Rough	8	0	Clean			3	Undulating	
12/07/12	672	655.33	54	145	3	2	5	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	SC to floor 672-Man bay. Large (30mm) qtz band following schistosity. Variable thickness.
12/07/12	675	658.26	60	126	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			2	Undulating	Void in L rib
12/07/12	677	660.21	70	36	1	3	4	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	1.5	Planar	
12/07/12	678.5	661.67	60	147	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	

12/07/12	680	663.14	59	150	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Coming into man bay schist dominant. Walls more blocky than broken
12/07/12	680.7	663.82																680.7-684 = man bay, L rib full SC
12/07/12	683	666.06	50	280	1	3	4	Joint	Fully Censored	Smooth	4	0	Clean	Intact rock	Invert	1	Planar	
12/07/12	683.5	666.55	58	145	4	2	6	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	
12/07/12	684	667.04	48	280	3	2	5	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	
12/07/12	685	668.01	55	150	4	2	6	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	Weathering increased to moderate. 685-687 R rib broken quite roughly - no joint sets
12/07/12	686.2	669.18																7mm band of weathered qtz/clay high weathering. 100mm down tunnel of band along schistosity
12/07/12	687	669.96																687-689 - rock broken (blast damaged) not along joints. Schist very dark with very frequent thin qtz bands (stripey again)
12/07/12	690	672.89	62	125	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
12/07/12	691	673.86	50	280	3	3	6	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	Both ribs highly continuous, spaced 25cm apart vertically for ~50m
12/07/12	691.7	674.55	56	140	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	SC to floor to 700 but lighter, less right down at invert

12/07/12	693	675.81	58	296	3	3	6	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	This jt plus schistosity are 2 main sets. Schist dark with fewer bands of qtz but seem to be less structurally controlled by schistosity. Breaking preferentially on joint.
12/07/12	695	677.76	60	150	3	2	5	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	
12/07/12	697	679.71	50	280	2	3	5	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	Tunnel raining, no clear schistosity
12/07/12	698	680.69																To 650 - Rock quite broken, no clear joints. SC heavily to floor
12/07/12	699	681.67																699-650 Rock has very large (20mm) qtz bands along schistosity. Seems more intact less breakage along schistosity. Very wet.
12/07/12	700	682.64	50	140	3	3	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
12/07/12	700	682.64	60	261	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	Very wet, flowing down L rib, dripping in R rib. L rib to 3m no distinct jt sets.
12/07/12	702	684.59																Definite boundary between lighter grey schist down tunnel and much darker schist up tunnel. Qtz bands throughout all but somewhat thicker up tunnel - weathered too. Boundaries of qtz 'infill' along schistosity = conduits for water. May have once had clay, now open (blasting?).
12/07/12	703	685.57	60	139	3	3	6	Schistosity	Fully Censored	Smooth	3	2	Clean			1	Planar	No fill, just water
12/07/12	703.5	686.05	80	230	0	1	1	Joint	Uncensored	Rough	8	1	Clean	Intact rock	Intact rock	1.5	Planar	Highly weathered surface, water flowing out of aperture. R rib total SC, no useful features

12/07/12	704	686.54															704-705m rock very broken, dark and 'stripey' again, breaking along qtz bands. No clean joint surfaces
12/07/12	705.2	687.71	60	156	3	2	5	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	
12/07/12	705.5	688.00															Very high qtz content, 200mm section of 80-90% qtz, very milky. 705-707m very stripey, not breaking along joint sets
12/07/12	707	689.47	60	130	3	2	5	Schistosity	Fully Censored	Rough	7	2	Clay			1.5	Planar	Fill highly weathered qtz/clay mix. Qtz fill increasing towards invert 0.5m from floor. 5cm wide, bright orange. Here to at least 710m schist lighter grey, far less water, less qtz bands (barely visible in places).
12/07/12	709	691.42	50	140	3	3	6	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	Qtz bands incr but still not very dominant. Void R rib.
12/07/12	710	692.39															SC to floor, heavy to 712m
12/07/12	711.5	693.86	50	74	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
12/07/12	712.2	694.54	50	136	3	3	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
12/07/12	713	695.32															Schistosity as above, rock very broken, no clear joint sets
12/07/12	715	697.27	62	168	3	3	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	(Scanline 10m ahead of tunnel measurements (tunnel says 705m))
12/07/12	716	698.24	60	232	2	2	4	Joint	Fully Censored	Slightly Rough	6	0	Clean			3	Undulating	

12/07/12	717	699.22	62	160	3	3	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
12/07/12	717.4	699.61	86	264	2	2	4	Joint	Fully Censored	Slightly Rough	6	0	Clean			3	Undulating	SC to floor to 730m
12/07/12	719.5	701.66	42	290	1	3	4	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	3	Undulating	
12/07/12	719.6	701.75	58	150	3	3	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
12/07/12	720.6	702.73	50	143	1	2	3	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	1.5	Planar	No clean surfaces. Rock very wet (only lightly shotcreted).
12/07/12	721.4	703.51	64	164	3	2	5	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	Void tall and thin, weathered surface but dry now, not broken on joint
12/07/12	722.5	704.58	70	95	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
12/07/12	723	705.07	85	220	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Undulating	
12/07/12	723	705.07	70	90	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	Clay band along joint, 100mm thick (shotcreted over). After clay band rock very broken. Large qtz bands eg. 20mm thick, zone 300mm thick of 5 large clay bands.
12/07/12	725	707.02	56	140	3	2	5	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	725m onwards, claybands ~300mm spacing (thinner than above), grey clay/crushed rock fill. Rockmass broken.
12/07/12	726	708.00	50	180	3	2	5	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	Man bay. L rib very blocky, not on joints. Dripping

12/07/12	726.5	708.48	63	236	2	2	4	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
12/07/12	727	708.97	50	308	0	1	1	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
12/07/12	727.7	709.65	50	68	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	
12/07/12	729	710.92	56	158	3	3	6	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	
12/07/12	729	710.92	57	284	1	2	3	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	3	Undulating	
12/07/12	730	711.90	70	56	2	2	4	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	
12/07/12	731	712.87	50	228	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
12/07/12	731.7	713.55	50	152	3	3	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Large void along schistosity
12/07/12	732	713.85																732-734 L rib rubbly, no clear surfaces. Dark highly banded schist again.
12/07/12	734	715.80	48	158	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	734-738.5m Man bay. Full SC. Very foliated. Very wet, dripping a lot, small waterfall in corner of bay.
12/07/12	738.3	719.99	55	145	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Rock at 738 light grey, well indurated, hardly any qtz bands. Broken along schistosity but not easily.

12/07/12	740	721.65	88	220	1	2	3	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
12/07/12	741	722.62																Rock stronger, not breaking as clearly along schistosity
12/07/12	742	723.60	62	154	3	3	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Walls uneven but not on joints (rock better indurated). More qtz bands coming in, weathered. Block size decrease. Broken along schistosity
12/07/12	743	724.57	58	168	3	3	6	Schistosity	Fully Censored	Rough	7	0	Clean			1.5	Planar	
12/07/12	744.5	726.04	35	182	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	
12/07/12	747	728.47																Walls very broken and blocky, very wet (flowing)
12/07/12	748	729.45																748-750m walls very smooth but SC to floor
19/08/12	750	731.40																Blocky, not too bandy.
19/08/12	751	732.38	53	158	4	2	6	Schistosity	Fully Censored	Slightly Rough	5	0	Clean			1.5	Planar	
19/08/12	751.2	732.57	72	282	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		3	Undulating	
19/08/12	752.4	733.74	60	152	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	

19/08/12	752.8	734.13	60	226	0	2	2	Joint	Censored Below	Rough	8	0.2	Clay	Intact rock		3	Undulating	Weathered yellowy brown coating on really R joint
19/08/12	754	735.30	80	270	0	2	2	Joint	Censored Below	Rough	8	0.5	Clay	Intact rock		1.5	Planar	
19/08/12	754	735.30	56	138	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
19/08/12	755	736.28	88	257	0	1	1	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
19/08/12	756	737.25																Void 80cm into ribs
19/08/12	757	738.23	34	282	2	2	4	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
19/08/12	758.5	739.69	62	241	1	2	3	Joint	Fully Censored	Rough	8	0	Clean	Intact rock	Invert	3	Undulating	
19/08/12	759	740.18	85	111	1	2	3	Joint	Fully Censored	Rough	8	0.5	Clay	Intact rock	Invert	1.5	Planar	
19/08/12	759	740.18	54	144	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
19/08/12	760	741.15	68	198	4	2	6	Joint	Fully Censored	Slightly Rough	6	0.5	Clay			3	Undulating	Picture 0462, Halos of weathering ~100mm out from joint. Shear on schistosity 10mm, weathered mica/clay in zone
19/08/12	760	741.15	55	142	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			2	Undulating	

19/08/12	760.5	741.64															Full SC from man bay in both ribs
19/08/12	761	742.13															Man bay 761-768m
19/08/12	765.3	746.32	32	244	4	2	6	Shear	Fully Censored	Smooth	4	40	Clay			1	Planar	Clay sample
19/08/12	769	749.93	51	313	0	0.5	0.5	Joint	Uncensored	Smooth	4	0	Clean	Intact rock	Intact rock	1	Planar	
19/08/12	773.5	754.32	63	173	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Schistosity offset by shear band (below). Measurement taken above shear.
19/08/12	773.5	754.32	27	138	4	2	6	Shear	Fully Censored	Smooth	4	20	Clay			2	Undulating	Visible in both sides, mod-high weathering halo. Steeper in R rib (parallel to schistosity). 0.5m below shear large brokencrushed qtz vein, following schistosity.
19/08/12	773.5	754.32	50	173	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Schistosity below shear
19/08/12	777	757.73	50	173	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			2	Undulating	Picture 0478. L rib very broken. Water flowing, rock shattered, moderately weathered. Fine bands in the schist, folds at m scale.
19/08/12	778	758.71															Large clay shear undulating/folding on schistosity. Weathering up tunnel of shear. Up tunnel schist planar again. Joints dripping. Photo 5616. Crushed quartz bands either side, weathering increasing, whole zone up to 300mm. Clay/crush 150mm wide.
19/08/12	779	759.68	54	172	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
19/08/12	780	760.66	50	147	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Up to 785m tunnel walls very homogeneous, thin banding within schist.

19/08/12	785	765.53	78	98	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	
19/08/12	790	770.41	52	158	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Foliation stronger
19/08/12	792	772.36	45	143	4	2	6	Shear	Fully Censored	Smooth	4	20	Clay			1	Planar	
19/08/12	794	774.31	62	142	4	2	6	Shear	Fully Censored	Smooth	4	10	Clay			1	Planar	Weathering increasing, 10mm clay bands along schistosity every 0.5m for 2m. Clay bands affecting dip of schistosity
19/08/12	796.5	776.75	65	138	4	2	6	Schistosity	Fully Censored	Smooth	3	10	Quartz			1	Planar	Clay bands stop, 10mm quartz bands instead. 5cm spacing max.
19/08/12	797	777.23																SC to floor L rib to 799m
19/08/12	799.5	779.67	50	63	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	3	Undulating	
19/08/12	800	780.16																Rock more intact, less banded, only fine quartz bands. Muck bay R rib 803-813m. Full SC from 800-817m
19/08/12	817	796.74	60	149	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
19/08/12	817	796.74	74	35	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	1.5	Planar	817-800ish rock blocky. From 817 up rock broken.
19/08/12	820	799.66	71	156	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	

19/08/12	821.3	800.93	65	280	0	2	2	Joint	Censored Below	Smooth	4	0	Clean	Intact rock		1	Planar	Tunnel wet again
19/08/12	822	801.61																822-828 thick SC both sides
19/08/12	828	807.47	65	140	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
19/08/12	830	809.42																Lighter SC to floor both sides, no joints visible
19/08/12	830.7	810.10																Large qtz band picture 0483
19/08/12	831.7	811.07	72	157	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	No clay banding, fine, highly banded.
19/08/12	836	815.27	65	151	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
19/08/12	836	815.27	32	307	4	4	8	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
19/08/12	836.5	815.76	30	292	4	4	8	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	
19/08/12	837.2	816.44	65	149	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
19/08/12	840	819.17	55	258	0	3	3	Joint	Censored Below	Rough	8	0	Clean	Intact rock		1.5	Planar	1/2 barrels

19/08/12	840	819.17	65	144	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
19/08/12	841	820.14																Digger bay to 850m
19/08/12	844	823.07	68	145	3	2	5	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Picture 0496, gneissic banding
19/08/12	845.5	824.53	58	193	0	2	2	Joint	Censored Below	Rough	8	0	Clean	Intact rock		3	Undulating	
19/08/12	847.5	826.48	40	280	2	2	4	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	Rock very broken again (blast damaged?)
19/08/12	850	828.92	67	137	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
19/08/12	852.5	831.36	72	138	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
19/08/12	853	831.85	25	270	4	4	8	Joint	Fully Censored	Rough	8	0	Clean			3	Undulating	
19/08/12	854	832.82	64	137	4	2	6	Schistosity	Fully Censored	Smooth	3	20	Quartz			1	Planar	Large 200mm zone of quartz bands
19/08/12	855.7	834.48	60	136	4	2	6	Schistosity	Fully Censored	Smooth	3	0.1	Clay			1	Planar	
19/08/12	857	835.75	38	284	2	2	4	Joint	Fully Censored	Smooth	4	2	Clay			1	Planar	Rock has larger quartz bands

19/08/12	858	836.72	74	156	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Rock strong, blocky walls
19/08/12	859	837.70																To 860 walls blocky, not breaking along schistosity or joints.
19/08/12	860	838.67	86	257	0	1	1	Joint	Uncensored	Rough	8	1	Clay	Intact rock	Intact rock	3	Undulating	
19/08/12	862	840.62	75	145	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	RQD improved slightly
19/08/12	864	842.57	87	259	2	2	4	Joint	Fully Censored	Rough	8	0.1	Clay			3	Undulating	
19/08/12	864	842.57	56	220	1	2	3	Joint	Fully Censored	Rough	8	0.1	Clean	Intact rock	Invert	1.5	Planar	
19/08/12	865	843.55	70	157	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Schist strong, breaks in rock every ~1m, banding very intact between.
19/08/12	866.5	845.01	69	155	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Shear along schistosity. Some clay, more proportion of crush. 3cm thick, weathering increases either side ~30cm.
19/08/12	870	848.42	68	158	3	2	5	Schistosity	Fully Censored	Very Smooth	1	0	Clean			1	Planar	Weathered gold biotite on joint surfaces.
19/08/12	870	848.42	28	236	0	1	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	3	Undulating	
19/08/12	872	850.37																Gneissic banding photos. (July)Face quite flat - Joint sets almost perpendicular to tunnel advance. Half barrels in walls 10m back from face (3+ rounds). Water from roof >12m back. One drill hole jetting 1.5m out from rib. 25l/s? Rock not too badly blast damaged, oxidation in face. Schistosity 62/138, consistent dips.

19/08/12	873.5	851.84	69	147	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Rock Highly Weathered. R rib SC to floor. Quite blocky, wedges popped out. Quartz bands a lot thicker
19/08/12	875	853.30	89	289	1	2	3	Joint	Fully Censored	Rough	8	0	Clean			1.5	Planar	Forming wedge with schistosity. Slight weathered coating on surface.
19/08/12	876	854.28	80	182	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Zones of 30cm large quartz bands, HW, 1m apart. Lots of water (from drilling of the face at 870m). Projecting 1m out from borehole one month after blasting
19/08/12	878	856.23	80	263	1	0	1	Joint	Uncensored	Rough	8	0	Clean	Intact rock	Intact rock	3	Undulating	Water coming out along joint
19/08/12	878.5	856.71	60	121	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	R rib still full SC
19/08/12	881	859.15	64	139	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Less wet. Wall not breaking along structures, relatively smooth (not blocky).
3/07/12	882	860.13	32	232	0	2	2	Joint	Censored Below	Slightly Rough	6	0	Clean	Intact rock		1.5	Planar	
3/07/12	883	861.10	68	148	2	2	4	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	
3/07/12	883	861.10	60	266	0	2	2	Joint	Censored Below	Slightly Rough	6	0	Clean	Intact rock		1.5	Planar	
19/08/12	884	862.08	22	271	2	2	4	Joint	Fully Censored	Smooth	4	0	Clean			1	Planar	
19/08/12	885	863.05	60	140	4	2	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	

3/07/12	885.6	863.64	68	236	1	2	3	Joint	Fully Censored	Slightly Rough	6	0	Clean			1.5	Planar	
3/07/12	885.6	863.64	62	124	2	2	4	Schistosity	Fully Censored	Smooth	3	0.5	Clay			1	Planar	At face - rock looks a lot harder - 1/2 barrels, synformal (zig zag) folding of quartz bands. Lots of water, face blasted on schistosity, quite flat gneissic schist
19/08/12	886	864.03																Thick full SC
19/08/12	893.5	871.34	76	160	3	3	6	Schistosity	Fully Censored	Smooth	3	0	Clean			1	Planar	Slightly blockier, under SC (rough measurement)
19/08/12																		Drilling face out, full steel into face and draining out of void in centre of face. Sketches in notebook.
19/08/12																		Still full SC, wet.

B.3 Core Logging

DRILLHOLE BORELOG SHEET PROJECT: Amethyst Hydro Ltd. LOCATION: Harihari	BH No:	1
	Date:	
	Logged By:	Erin

Box No.	STRATA DESCRIPTION Soil Description - Major colour, second colour, Subordinate fraction, minor fractions, - plasticity, bedding, moisture, structures Rock Description - Colour, fabric, rockname	Weathering				Strength Rock					Depth	Graphic Log	Joint Frequency	Joint Angle	DEFECT DESCRIPTION Joints, bedding, crush zones, and schistocity. Attitude, aperture, roughness, infill, RQD	Q			CORE LOSS	RQD % per 3m
		UW	SW	HW	D	VWk	Wk	M	St	VSt						Jn	Jr	Ja		20 40 60 80

	x				x	x	x	x	1	<2	1-2 natural joints, oxidised surfaces but no visible filling. Rough surfaces	4	1.5	0.75		
	x	x			x	x	x		2	3	Slight incr in joints, oxidisation incr along surfaces and up sides of jts. Jts running across foliation parallel to core. Surface rough, 1mm ap, no infill	6	1.5	1		
Unweathered, lt grey, foliated Schist. Fine grained, quartzo-feldspathic and biotite bands running parallel to foliation. Unweath - SW, Mwk-Mst. Bands vary in size, greatest 9mm.	x	x			x	x	x		2.3	2	Joints mostly parallel to foliation (iron stained), no filling, R, 0ap	4	1.5	1		70
	x				x	x	x	x	3	3	Jts follow foliation, R, 0ap, surface staining	2	3	1		
	x				x	x	x	x	4	2		4	2	3		
Quartzo-feldspathic bands less than 1mm, although can get up to 6-7mm in a few. Decrease in bands, rock morehomogeneous and grey.	x	x			x	x	x	x	4.9	5	Fewer joints on attitude of schistosity, core parallel set comes back. Surface and sides stained, micaceous gouge present, surfaces SR - Smooth.	6	2	3	0.4	80
Schist darkeneing - incr. biotite. Also incr. weathering and a few large (20mm) quartz bands.	x	x			x	x	x	x	6	3		2	3	1		
Large qtz bands gone, just thin banding. Some foliated textures like augen almost at 6, blobby bands rather than straight.	x	x			x	x	x	x	7.2	1	Joints only parallel to foliation. Slight surface staining and oxidation but otherwise no infilling or aperture. Rock not breaking along schistosity when forced, biotite bands incr,but no resulting lack of strength. Jt surfaces all rough. Section at 5m with large broken chunks (goes for 10cm). Section higher weathered but breaks not on joints. Whole section bounded by joints though.	2	3	1		60
	x				x	x	x	x	8	4		6	1	2		
	x				x	x	x	x	9	5	Foliation-parallel joints very smooth, micacous surface and iron staining up the sides. Fill 1mm thick. Core parallel joint surface very rough, slight iron staining. No infill.	4	3	2		
No large quartz bands, only very thin (<0.5mm). Biotite banded rather than pervasive, weathering decreases. Quartz bands increasing 8.6-9m	x				x	x	x	x	9.3		Only defect is foliation, very strong, not breaking along foliation. Qtz bands incr in frequency towards 9.3m	2	1	0.75		70
	x				x	x	x	x	10	2	joint following schistosity, micaceous filling, clayey. Sides stained, surface smooth, slight vuggy/dissolved texture either side of joint. Parallel joint to foliation, extremely rough, no filling (natural joint?)	4	2	2		60
	x	x			x	x	x	x	11	10	10.1-10.4=incr jts, broken zone at 10.3, less qtz bands through zone though. Surfaces rough with fine silty infill. No intact core through zone.	9	3	2		40
Incr in joints and subsequent iron staining, no change in rock	x				x	x	x	x	11.6	5	11-11.2 broken zone again.	9	3	1		
	x	x			x	x	x	x	12	7	11.6-12 joints mainly parallel to foliation, slight iron staining on surfaces. Joint set also runs across foliation, R, micaceous surface.	4	3	1		50
Qtz and biotite bands very thin, making the rock look relatively homogeneous. Incr frcturing and weathering.	x	x			x	x	x		13.2	7	Large joint parallel to core 12-12.5. Iron stained, R surface. Core broken along schistosity but not natural. Joints have micaceous surfaces (weathered biotite).	9	3	1		
Shear zone/crush. Starts at 13.2 as highly weathered-decomposed schist, light brown. Then a zone to 14m of soft light brown gouge material (silty and clayey). 13.8 light grey shards of parent rock visible, very angular clasts <20mm in size, mostly 5mm. Size decreasing toward 14m. Some qtz banding visible in light brown gouge near 13.4m	x	x	x	x	x	x			14	cru sh	No foliation visible except a few 'qtz bands' through gouge at 13.4. Whole zone is gouge/crush.	20	3	8		0

Change to PQ. 14-14.1=grey crush. Micaceous, clayey, very weak, moderately weathered. 14.1-14.4= Broken zone, slightly weathered. Rock still light grey, quartzo-feldspathic schist with thin qtz bands.	x	x	x	x	x		15	6	Crush 14-14.1, clayey, very weak. Broken zone to 14.4. Rock fragments slightly weathered indicating mutliple jt orientations but this doesn't continue through rock. Surface weathered and micaceous, Sr-R.	9	3	3		30
Light grey, unweathered qtzo-feldspthic schist with variable sized qtz bands, mainly thin but a few up to 6mm	x		x	x	x	x	16	4		4	2	1		20
	x		x	x	x	x	17.1	5	Defects all parallel to foliation, surfaces smooth, micaceous coating, less iron staining.	4	2	1		85
	x		x	x	x	x	18	6	Joints parallel to foliation, iron staining but minimal infill. 'Discing' in places along foliation. Surfaces smooth and core intact apart from that	4	2	1		
	x		x	x	x	x	19	5	2 joint sets, along foliation and one slightly across foliation (rough). Joint set along foliation smooth and iron stained as above but no fill. Micaceous surface.	6	2	1		50
	x	x	x	x	x	x	19.9	5	Long core parallel joint at 19m, pervasive through >50cm. Iron stained, rough surface, no fill or aperture. Other joints just foliation-parallel as above.	9	1.5	0.75		30
20.1 - Convoluted banding in schist, folding of quartz bands? Light grey UW-SW schist with quartzo-feldspathic and biotite bands running parallel to foliatio. Biotite flecks seem slightly weathered in places.	x	x	x	x	x	x	21	7	Joints parallel to foliation, iron stained and smooth micaceous surfaces. Some joints cutting across foliation too but no infill, only surface staining.	9	1	1		30
	x	x	x	x	x	x	22	2	Fewer joints, joints present follow foliation, smooth surface. One set crosses foliation, has weathered biotite rough surface.	4	1.5	1		65
Pervasive joint parallel to core	x	x	x	x	x	x	22.7	2	Pervasive defect runs down core for whole interval. Splits core in half, SR-R surface with light green clay (biotite weathered to chlorite?). Schistosity seems offset in places, but no indication of weathering or gouge (no sign of movement)	4	1.5	1		50
							22.9						0.2	
	x	x	x	x	x	x	24	5	Long core parallel joint at 22.9 carrying on from before core loss. Surface extremely smooth, slickensided. Weathering of biotite on the surface and some iron staining. Another joint set in this interval with extremely smooth surface, red brown micaceous/clayey gouge. Infill approx 1mm.	9	1	2		
As at 20.1	x		x	x	x	x	25	5	Joints primariliy follow foliation. Surface SR-Sm, iron stained.	4	1.5	1		
														70
Crush zone 25.65-25.8, slightly increased weathering but otherwise same as above	x	x	x	x	x	x			25.65-25.8 - Crush/broken zone. Clay rich, breaking along foliation at edges. Limonite visible and rock seems quite highly weathered in crush zone. Rock fragments within.	3->20				0
	x		x	x	x	x	27	6	25.8-26.8=Very few defects, parallel to foliation, smooth surfaces (unweathered micaceous surfaces).26.8=discing, 4-5 joints within small space, all along foliation. Iron stained micaceous surfaces, smooth.	3	2	1		70
	x	x	x	x	x	x	28	4		6	2	1		
	x		x	x	x	x	28.6	2	Very few defects, along foliation, slightly weathered with a smooth micaceous surface.	3	2	1		
Light grey schist, as above. Banding thin (mm scale), even qtz and biotite bands, with a few thicker ones (up to 6mm)	x		x	x	x	x	29	1	Discontinuities follow schistosity. Smooth micaceous surfaces, no change in schistosity type. Thin bands of qtz and biotite.	3	1	1		80

29.8= moderately weathered quartz bands. Quartz bands seem vuggy/dissolved in places and are light pinky brown colour through core	x	x	x	x	x	x	30	4	Joints follow schistosity but incr. iron staining on surfaces. Surfaces R, no infill. 29.8 staining more pervasive and seems to have leached to either side of defects.	3	1.5	2	50
	x		x	x	x	x	31.3	10	Discontinuities follow schistosity. Smooth micaceous surfaces, no change in schistosity type. Thin bands of qtz and biotite.	3	1	1	80
Light grey schist as above, a few shear zones and convoluted banding coming in.	x		x	x	x	x	32	2	Defects parallel to foliation, 31.75m defect has light brown clayey gouge fill with rock fragments >10mm. Surface of defect smooth. 31.8m defect runs steeply down core, not quite parallel. Rough iron stained surface.	4	1	3	
Folding(?) appearing in schist bands, core slightly more weathered but due to incr discontinuities, weathering not even through entire core.	x	x	x	x	x	x	33	9	Multiple orientations, creating broken zone for 20-30cm. All surfaces iron stained but rough and large biotite crystals seen on surfaces of foliation-parallel joints.	9	1.5	2	50
Increased 'discing' and a few zones of previous fluid flow (quartz veins weathered, dissolved/vuggy texture, areas of high weathering along joints permeating out into core)	x	x	x	x	x	x	34.1	14	Increased frequency of joints, all following foliation orientation. Surfaces rough with a micaceous gouge infill (<1mm), iron stained permeating out into core ~5mm from defects. 33.6m= vuggy qtz band, pinkish brown with weathering along joint surface. surface smooth with micaceous gouge (following foliation). Similar defect again at 33.8 but no qtz band, just within the schist	4	1.5	3	
Schist as above, broken zones and crush becoming more prevalent. Still mainly unweathered.	x		x	x	x	x	34.75	3	Defects following schistosity, R surfaces, iron staining but no infill	4	1.5	1	40
Broken zone-> crush	x		x	x			35.3	20	Broken zone - initially joint set cutting foliation becomes more frequent then brokwn zone to 35.3. Mainly unweathered still, with a little blueish-grey clay in the most broken part. Intact 'discs' of quartz bands (along foliation orientation) and evidence of micaceous surfaces. Surfaes smooth.	20	1.5	3	0
	x		x	x	x	x	36	2	Defects following schistosity, R surfaces, iron staining but no infill	4	1.5	1	
Schist as above, broken zones and crush becoming more prevalent. Still mainly unweathered.	x		x	x	x	x	37.2	5	Defects following schistosity, R surfaces, iron staining but no infill	4	1.5	1	60
	x		x	x	x	x	38	0	Foliation present, no natural joints. Foliation as above, increasing biotite bands.	3	4	0.75	100
	x	x	x	x	x	x	39	4	Defects both parallel to foliation and perpendicular. Increased weathering of rock and of qtz bands, joints mainly rough but planar with no infill but some iron staining.	6	1.5	1	80
Light grey foliated schist, increased weathering.	x	x	x	x	x	x	40.2	9	As above, but with some 'discing' occurring at 39.6m, possibly drill related as no associated iron weathering.	6	1.5	1	30
	x	x	x	x	x	x	41	3		3	1.5	1	
	x		x	x	x	x	42	2	Joints follow foliation, slight iron staining and micaceous surfaces but this is not pervasive into sides of joints. Surfaces rough. One joint perpendicular to foliation, rough, no iron staining.	4	3	1	70
Schist as above, thin foliation bands but still variable, joints and weathering decreased.	x		x	x	x	x	43.1	2	Defect parallel to foliation, slightly weathered and has a smooth clayey-micaceous	3	1.5	3	100

										surface (fill <1mm), continues slightly into sides of joint.					
17	BOX 17 MISSING							45.8							
		x		x	x	x	x	47	4	Joints cut foliation. Surfaces rough and little to no iron staining. Rock breaks apart along foliation but these seem not to be natural joints as can be induced after a few blows of a hammer.					85
	Rock strong but will break apart under hammer along foliation after a number of good blows.	x		x	x	x	x	48	2	Joints as above, surface slightly rough, more iron staining and a fine grained coating on surface (clay). Some biotite coating also present.					95
		x		x	x	x	x	48.7	2						80
	Light grey unweathered quartzo-feldspathic/biotite schist. Bands of biotite and quartz becoming more distinct from each other. Larger bands of quartz coming in around 50m.	x		x	x	x	x	50	4	Core intact till 49.4m, then crossing joints create a broken zone. Joints perpendicular to foliation, have rough micaceous surfaces, with evidence of weathered biotite and iron staining throughout this zone.	9	3	2		70
		x		x	x	x	x	51	0	Rock primarily intact with one defect along foliation orientation, but may be drill induced as no iron staining visible and surface rough.					
		x		x	x	x	x	51.6	1						100
		x		x	x	x	x	53	3	Defects primarilly along foliation, R surfaces with some micaceous coating but no iron staining	2	1.5	0.75		
		x		x	x	x	x	54.5	3	Defects parallel to foliation, smooth surfaes with micaceous coating ~1mm, no visible weathering or alteration of surface though. Defects perpendicular to foliation show rough surfaces, slightly weathered.	4	2	1		85
		x		x	x	x	x	56	2	Defects perpendicular to foliation, rough surfaces with slight iron staining. Widely spaced. Schistosity still closely spaced and core breaks along it with a few blows of the hammer.	4	3	1		80
	As above	x		x	x	x	x	57.15	3	Natural joints follow schistosity but have slight iron staining up sides into core. Also have dark biotite micaceous coating on surface mking surface smoother but still SR.	4	1.5	2		90
		x		x	x	x	x	58	1	Joints forming parallel to foliation, exhibiting smooth micaceous surfaces, <1mm ap. Surfaces slightly weathered to reddish brown but no extensive iron staining. Foliation as previously - thin <1mm scale bands of biotite and qtz. Thickest bands ~3mm. some complex banding taking place (see core photos)					
		x		x	x	x	x	59	2						100
	More 'convoluted' folding of bands but still light grey quartzo-feldspathic biotite schist.	x		x	x	x	x	60.3	2						90
	Weathering increased slightly at 60.4m, quartz banding becoming more prominent, with a ~5mm band every 200mm. Weathered quartz bands causing defects to form parallel to foliation. Large quartz band coming in at 61.2m, 30mm thick.	x	x	x	x	x	x	61	1						85
		x	x	x	x	x	x	62	2						
		x	x	x	x	x	x	62.9	2	Joints parallel to foliation as above. Clayey micaceous fill gives smooth surface. Foliation creates weakness in rock, when hit it wil break apart on qtz bands, but otherwise rock between the bands is quite intact.	4				
		x	x	x	x	x	x	64	0	No natural joints visible. Schistosity as above, slightly more weathered and will break along this if induced (forming a weakness in rockmass)	2	1.5	0.75		
	As above, large quartz band at 63.6m. Slightly weathered, qtz bands becoming more frequent	x	x	x	x	x	x	65	1	As above, at 64.95 a moderately weathered quartzo-feldspathic band is prominent and causing a joint. Surface is slightly rough, micaceous and slightly clayey.	3	1.5	1		100
	Distinct dark and light (qtz and biotite) bands becoming very	x	x	x	x	x	x	65.9	4	Incr. banding leads to incr. weakness, one long jt forming parallel to core (rough surface).	9	1.5	3		40

interspersed, and a broken zone seen at 65.3m													Core also breaking along foliation-parallel jts which have smooth micaceous/clayey brown surfaces.					
	x			x	x	x	x		67		2		Rock breaking less easily along defects, a few joints visible cutting perpendicular to foliation. Overall few joints, surfaces are rough with no iron staining or incr weathering but a silty infill on them.	4	1.5	3		
66.2m interspersed bands decreasing, back to banding as before. Frequency of larger qtz bands still ~200mm	x	x		x	x	x	x		68		1			4	1.5	3		
	x			x	x	x	x		68.9		0			2	1	0.75		
As above, large quartz band (10mm) at 69.05. Banding continues to 69.45, UW	x			x	x	x	x	x	69.45		0		No natural joints, schistosity as above.	3	4	0.75		
Banding becomes larger and very convoluted (separate dark and light bands very prominent), weathering has increased. 69.7 qtzo-feldspthic bands vuggy, highly weathered. Voids up to 8mm size within qtz bands. All highly weathered.	x	x	x	x	x	x	x	x	69.9		3		Jt surfaces highly weathered, micaceous dark brown gouge with clay, very smooth and planar. To either side of joints rock highly indurated.	9	1	3		
	x	x		x	x	x	x		71		1		As above, no natural joints, a few large quartz bands, weathering of these decreasing. Surface of joints parallel to foliation smooth with micaceous gouge	4	1	1		95
As at 69.45, weathering decreased and large quartz band frequency decreasing	x	x		x	x	x	x		71.6		0		No natural joints, foliation back to interspersed banding with few large qtz bands	2	4	0.75		
	x			x	x	x	x		72		1		One joint, cuts perpendicular to foliation. Surface rough, iron staining on surface and up sides.	4	3	2		
	x			x	x	x	x		73		3		Same as set above, but another joint parallel to foliation comes in, iron stained surface also. These sets make slight broken zone at 72.5m	9	3	2		75
Light grey schist as above. Prominent quartz bands have decreased, core is unweathered.	x			x	x	x	x		74.5		3		One set runs parallel to core (300mm long), rough surface, no iron staining or infill. Other sets parallel to foliation with smooth surface, slight micaceous fill.	4	2	0.75		83
Light grey unweathered quartzo-feldspathic/biotite schist. Weathering increasing at 75.6m, as a long core parallel joint set comes in. Vuggy quartz bands are seen again but only slightly vuggy, no large voids.	x			x	x	x	x		75.6		2		Joint parallel to foliation and formed by one moderately weathered quartz band right near 74.5. Surface rough with iron staining	4	1.5	1		75
	x	x		x	x	x	x		76.7		7		Loong core parallel joint cuts core in half through whole interval. Surface rough but iron stained and evidence of clay filling. Other foliation parallel joints cut this section creating a slight broken zone. Surfaces of these rough with micaceous coating.	9	3	2		0
76.7m back to largely unweathered schist with frequent thin quartz bands	x			x	x	x	x		77.4		1		Joint parallel to foliation, iron staining on surface and up sides, smooth micaceous surface.	4	1	2		75
	x			x	x	x	x		78		0		No natural joints, only a few induced breaks along foliation. Schistosity as above, frequent qtz bands but still 5-10mm scale.	2	1	0.75		100
Dark flecks of biotite merging into round blobs. Otherwise foliation and rock much the same. UW-SW	x			x	x	x	x		79		1		1 joint set cutting perpendicular to foliation. Surface is rough, iron stained and sandy/silty. Foliation around this joint shows increased weathering and decreased strength.	4	3	2		95
Banding becomes more prominent and at 79.9 this weakens core which shows increased joint sets along foliation.	x	x		x	x	x	x		80.3		9		Increased banding frequency and size up to 80m, then increased joints parallel to foliation. Surfaces are smooth, SW and micaceous.	4	1	1		55
Light grey schist as above, banding frequency decreased and very few prominent qtz bands.	x			x	x	x	x		81		1		schistosity less prominent, natural joint following schistosity orientation. Surface smooth and micaceous with slight iron staining.	3	1	1		70

Broken zone coming in at 81.1m - intersection of 2 jt sets. Continuing through interval	x	x	x	x	x	82	10	Interval shows 2 main broken zones formed from intersection of foliation-parallel jt set and foliation-perpendicular jt set. Surfaces rough with slight clay coating	9	1.5	1	55
No change in rock, banding toned down, rock looks more homogeneous. A few prominent dark (biotite) bands after 83m.	x	x	x	x	x	83.2	4	Joints following foliation orientation, surfaces rough with light grey silty/clayey coating.	3	1.5	1	90
	x	x	x	x	x	84	1	I joint follows foliation. R surface but micaceous/clay infill (2mm) and iron staining.	4	1.5	3	
	x	x	x	x	x	85	0	No natural joints, foliation continues as above. Rock still beaks along foliation if forced.	2	1	0.75	100
Unweathered light grey quartzo-feldspathic bitotie schist. Quartz bands becoming prominent again, still thin though	x	x	x	x	x	86.2	5	Foliation perpendicular joint set present. Surfaces are rough with iron staining, silty coating and light green clay (chlorite?) present. Foliation parallel joints show smooth micaceous surfaes.	9	1.5	1	
	x	x	x	x	x	87	5	Multiple joint sets cutting foliation. One set steeper than the other. This has rough surface, no evidence of fill. Second set has slight iron staining up sides, R surface but micaceous gouge present. Last set is foliation parallel and is highly weathered. Silty/clayey coating on surface. Weathered biotite on surface.	9	3	2	60
	x	x	x	x	x	88	1	Few natural joints, they are foliation parallel and have rough surfaces with micaceous coating. A few prominent qtz bands are coming in along foliation, but otherwise schistosity largely unchanged.	3	1.5	1	
As above. A few joints with increased weathering halos.	x	x	x	x		89.1	1		3	1.5	1	100
Larger qtz bands/zones coming in to 90.1. Zones 30-70mm long. Bands every ~300mm or less. Rock still largely unweathered except for the odd weathered biotite.	x	x	x	x	x	90	2	Mainly jts parallel to foliation but one joint cutting parallel to core. Surface rough and undulating and no iron staining or coating.	6	3	1	
	x	x	x	x	x	91	1	Joints parallel to foliation. Surfaces rough but with micaceous coating and little to no iron staining.				
	x	x	x	x	x	91.9	1					95
Larger qtz bands continue and bands now quite purely qtzo-feldspthic. Darker zones of concentrated biotite also appearing.	x	x	x	x	x	93	0	Some discing at start of interval but from drilling, not natural. No natural defects except foliation which is still broken along after a few blows of hammer	2	1	0.75	70
Large bands mainly disappear but weathering incr. slightly and some slight 'vuggy texture comes back.	x	x	x	x	x	94	2	Jt perpendicular to foliation, surface R with no staining or coating. Another set parallel to foliation, shows iron staining up sides and clayey coating. Surface smooth.	9	1	1	
	x	x	x	x	x	94.9	4		9	2	3	80
	x	x	x	x		96	3	Rock broken easily along foliation, particularly on edges of qtz bands. Clay shear at 95m follows schistosity orientation. Break along foliation at 95.2 shows zone of almost pure biotite bands which core is breaking along.	6	1	1	90
Light grey, unweathered qtzo-feldspthic schist with variable sized qtz bands, mainly thin but a few up to 50mm. Broken zone coming in at 96.8m	x	x	x	x		97.2	9	Zone of increased banding at 96.5, rock breaking along dark biotite bands. 96.8m=broken zone. 2+ jt sets causing it, surfaces are rough with clay/silt fill and some iron staining. Mica also present where breaks occur on foliation.	12	1.5	3	55
	x	x	x	x		97.8	6	Few natural jts, occurring along foliation orientation. Some iron staining into sides and surfaces smooth with reddish-brown clay coating.	4	1	3	80
Light grey schist as above	x	x	x	x		98.5	0	No natural joints, only a few induced breaks along foliation. Schistosity as above, frequent qtz bands.	4	1.5	1	70

Increased weathering of qtz bands but country rock still UW. 99m small pinkish nodules within banding. Increased banding in this section and through to 99.5m. Bands very contrasting light and dark. Core harder than previous	x		x	x	x	x	99.5	3	Qtz bands becoming weathered. Natural joints following foliation. Visible through iron stain halo. Forming along boundaries of qtz bands. Surfaces rough and slightly iron stained.	4	1.5	2		
A few large quartz bands but otherwise just foliated schist. Some bands seem to be folded	x		x	x	x	x	100.5	1	Very few natural joints, forming along foliation as above, surface smooth with micaceous/clay gouge and slight iron staining	4	1	3		98
	x	x	x	x	x	x	101.5	2	Very few joints, cutting perpendicular to foliation, with R surfaces and slight silty coating (0ap). Foliation as above but with slight weathering along qtz veins in places.	4	1.5	1		100
Light grey unweathered quartzo-feldspathic/biotite schist. Mainly homogeneous with a few larger quartz bands. Broken zone at 103.5	x	x	x	x	x	x	102.5	5	Main set cutting parallel to foliation, creating slight broken zone (from breaking into core box?). Surfaces reddish brown micaceous coating, SR to Sm, evidence of light brown clay on surfaces.	4	1	2		70
	x		x	x	x		103.4	8	Broken zone at 103.5, mostly along foliation-parallel joints as above, but some cutting foliation too. Surfaces smooth and micaceous/clayey, not much weathering or iron staining.	9	1.5	3		60
	x		x	x	x	x	104.5	8						
As above	x		x	x	x	x	106.3	3	A number of clay filled joints/shears parallel to foliation are present. Surfaces are smooth with micaceous walls and light grey/blue clay filling. Aperture ~1mm but difficult to tell due to drilling. No other joint sets visible.					45
	x	x	x	x	x	x	107	3	Long core parallel jt appears at 106.5m. R surface, slightly iron stained, no visible fill. Area around jt shows incr. weathering on qtz bands.	9	1.5	2		
Light grey schist, more joint sets coming in and weathering has increased. Foliation quite variable and zones of thicker qtz bands coming in >50mm wide.	x	x	x	x	x	x	108	9	Core parallel jt continues through whole interval. 107.1m well indurated qtz band cut by this jt, shows vuggy texture again. A few foliation parallel jts cut long jt, until broken zone at 107.5. Surface iron stained with silty coating. After broken zone foliation banding very convoluted and not clear.	9	1.5	3		
	x	x	x	x	x	x	109.3	6	Return to 'normal' schistosity, few larger qtz bands, jts cutting parallel to foliation and exhibiting smooth micaceous surfaces. 108.5m dark biotite rich band has disced easily along mica foliations.	4	1	3		55
	x		x	x	x		110	1	Broken along biotite band. Shows coating of biotie and greyish-blue clay. Surface smooth, aperture 1mm	4	1.5	1		
Foliation mainly returned to normal with fewer large qtz zones. Core relatively broken up as shown by RQD, but drill related rather than defect related. Mainly UW	x		x	x	x	x	111	2	Jt set crosses perpendicular to foliation. Surface rough but iron staining and coating of fine light brown silt visible. Another jt follows foliation orientation, S.R. surface but same light brown silt fill as other jt.	9	1.5	3		
	x		x	x	x	x	112.1	2	Follow foliation orientation, reddish brown surface, smooth, with ~1mm of fill.	4	1	3		78
Schist as above, thin foliation bands but still variable, joints increased but rock still largely UW. A few large qtz bands but mainly thin banding and	x		x	x	x	x	113.5	12	Surfaces of foliation-parallel joints smooth with micaceous and/or clay fill. Apertures <1mm. One joint parallel to core cuts core in half from 113-113.5m. Smooth surface, iron stained and clay coating	9	1	3		70

almost homogeneous texture.																
A few slightly larger qtz bands but mainly uniform schistosity till 114.5 where convoluted texture comes in and bands are not as distinct.	x		x	x	x	x	115.1		3		Joints parallel to foliation. Surfaces rough but with micaceous coating and little to no iron staining.	4	1	3		
Following from convolluted bands above bands at 115.1 continue to be convoluted and increase in distinction (thin bands of distinct dark and light) untill 115.5 where weathering increases a lot throughout rockmass.	x	x	x	x	x	x	115.7		4		Rock does not break easily along foliation. Main joint is a long core-parallel joint coming in in the more weathered rock.Surface is R but slightly iron stained	9	1.5	1		
Rockmass returns to normal banded schistosity with a few larger qtz veins every ~300mm. Few joints mainly follow foliation orientation	x		x	x	x	x	117.8		3		Natural joints follow schistosity and have dark biotite micaceous coating on surface making surface smoother but still SR. Breaking along edges of qtz bands.	4	1.5	1		
	x		x	x	x	x	118.65		0		Rock breaking along foliation but no joints. This gives breaks a smooth dark micaceous surface but no iron staining or clay fill is present	2	1	0.75		
Shear zone at 118.65, 130mm thick. Interval following shear is very broken but still mainly unweathered. Rock either side of the shear zone looks similar to rock above (box 42), banding has decreased slightly and there are few if any prominent qtz bands. Rock is still quite strong to either side of shear zone.	x		x	x	x	x	119.2		10		Shear zone at start of interval shows blue-grey clay gouge filling. Can be indented with finger, shows fragments of qtz and biotite within. Qtz fragments subrounded to angular. After zone rock returns to 'normal' but a broken zone on multiple jt sets occurs. Surfaces of jts are iron stained, with light brown clay coating.	12	1.5	8		
Rock continues to be broken but is overall similar to box 42, still has a lack of prominent qtz bands. Incr. in amt of biotite, more dark flecks through core.	x		x	x	x	x	120.4		25		Broken zone continues as above, less iron staining on jt surfaces. All surfaces R, minor silt coating in places. Multiple joint orientations.	12	1.5	3		34
Rock mainly intact again, with a few larger qtz bands than previously.	x		x	x	x	x	121		3		Joints following foliation , surfaces smooth with light blue-grey clay coating.	4	1	3		
Interval begins with broken zone grading into another shear zone, approx 300mm. Broken zone continues throughout interval, rock either side remains hard and mainly unweathered (SW through shear zone), and strong.	x	x	x	x			122		20		Shear zone shows blue-grey clay gouge filling. Can be indented with finger, shows fragments of qtz and biotite within. Qtz fragments subrounded to angular. Before and after zone rock returns to 'normal' but a broken zone on multiple jt sets occurs. Joint surfaces are iron stained and rough.	20	1.5	8		
Rock returns to largely unbroken light grey unweathered quartzo-feldspathic-biotite schist. Few slightly larger qtz veins, natural joints also present.	x		x	x	x	x	123.7		4		One set perpendicular to foliation, R surface, no staining or coating. Most other jts parallel to foliation orientation, show micaceous/grey clay filling up to 2mm thick.	6	1	3		50
Increased frequency of ~5mm scale qtz bands. Variable through interval and not associated with jointing.	x		x	x	x	x	125.5		8		Joints smooth, iron stained with light brown clay fill. Follow orientation of foliation mainly, 1 set crosses perpendicular to foliation. Staining halo ~10mm out from jt either sides.	9	1.5	2		
Biotite flecks seem to have returned to random, not lined up in bands. Core unweathered.	x		x	x	x	x	126.5		4		More joints perpendicular to foliation, iron stained/clay surface, R.	9	1.5	2		79

Light grey schist, a few large qtz bands (20mm). 126.8m Banding becomes very defined, thick dark and light bands untill 127.1m. Very undulating and the zone has thin bands of highly weathered biotite within.	x	x	x	x	x	x		127.1	0	No natural joints, rock seems well indurated. Schistosity is undulating and includes bands of highly weathered biotite, which don't seem to weaken rockmass.	2	2	0.75	
	x	x	x	x	x	x		128	1	1 joint cuts perpendicular to foliation, surface is R with slight iron staining.	4	3	1	
Rock returns to largely unbroken light grey unweathered quartzo-feldspathic-biotite schist. Few slightly larger qtz veins, natural joints also present.	x		x	x	x			129.4	6	Rock breaking along foliation, small broken zone at 129m shows a number of these joints causing discing, surfaces are clay filled with iron staining, but R.	4	1	3	90
As above	x		x	x	x	x		130.4						
Darker banding comes in here, rock still unweathered but darker grey schist surrounds bands of qtz and flecks of biotite.	x		x	x	x	x		131.1		No natural defects but rock breaking along schistosity, exhibiting smooth micaceous surfaces. No iron staining or other fill present				
Return to light grey quartzo-feldspathic-biotite schist as above, a few prominent qtz veins variably scattered throughout.	x		x	x	x	x	x	132.2	2	Natural joints follow schistosity but have slight iron staining up sides into core. Also have dark biotite micaceous coating on surface mking surface smoother but still SR. Slight silty coating on joint surfaces.	4	1.5	3	
	x		x	x	x	x		133	2	Natural joints follow schistosity and tend to break at the edges of large qtz veins. R surfaces but clay and mica coating making them slightly smoother.	4	3	1	
	x		x	x	x	x		134	2		4	1.5	1	
As above, foliation very thin with variable thicker qtz bands. A few broken zones are present but overall core is UW.	x		x	x	x	x		134.8	9	Broken zone at 134m. Surfaces SR with light brown silty coating. No iron staining. Joints cut perpendicular to foliation. Rock either side is very well indurated.	9	1.5	3	95
	x		x	x	x	x		136	5	Joints ocurring perpendicular to foliation. Surfaces rough with light brown clayey coating.	9	3	3	
	x	x	x	x	x	x		137	10	Going into a broken zone at 136.3m, multiple joint orientations. Slight iron staining on rough surface.	9	1.5	1	
Weathering increasing slightly after broken zone at 136.3m	x	x	x	x	x	x		137.7	3	Joints follow foliation orientation, surfaces smooth with micaceous/clay coating	4	1	2	63
	x		x	x	x	x		139	4	Joints following foliation , surfaces smooth with micaceous coating. Light brown clay also visible and evidence of iron stained halos up sides.	4	1.5	2	
Schist as above, largely unweathered but alteration halos where joints are running parallel to foliation. Core largely homogeneous, less distinct banding and prominent qtz bands thin (3mm). Highly weathered zone at 140.5m	x		x	x	x	x		140.6	8	Joints follow foliation orientation, large alteration halos to either side and surfaces coated with reddish-brown clay fill (1-2mm thick). Foliation unchanged. Highly weathered zone at 140.5, rock still quite well indurated, vuggy texture again and rock dark reddish colour.	4	1	3	85
	x	x	x	x	x	x		142	1	Joint running perpendicular to foliation. Right at 140.6m, so end of highly weathered section, surface rough and some iron staining. Foliation remains the same with incr. of large qtz bands.	4	3	1	
Weathering decreased again from 140.6m. Large qtz bands coming back in (10mm) every ~200mm. Whole interval overall less jointed than above. Large qtz veins disappear at 143m.	x	x	x	x	x	x	x	143.4	3	Jointing runs parallel to foliation orientation, surfaces smooth with light grey-blue clay coating (<1mm).	9	1	1	
A few qtz 'blobs' at 143.5m (not full bands), prominent qtz bands continue through but much thinner than above (2-3mm).	x	x	x	x	x	x		145	1	Joint cuts perpendicular to foliation. Surface rough (stepped) with mica and light brown clay coating.	4	1.5	3	95

Otherwise schist as before, weathering decreases.	x				x	x	x	x		146.2		2		Joints along foliation orientation, surfaces R with blue-grey clay fill (1-2mm). A few qtz bands cut perpendicular to foliation , same orientation as jt above, but core not breaking along margin.	4	1.5	3		
	x				x	x	x	x		148		4		2 sets, one perpendicular to foliation: R surface, micaceous coating and slight iron staining.Parallel to foliation: SR surface with 0.5mm coating of mica and some weathered mica. Less iron staining.	9	1.5	1		
As above, qtz bands variable. Rock still UW, 148.3m starts zone of a few joints with thick clay fill.	x				x	x	x	x		149.2		9		Joints all parallel to foliation orientation, surfaces show 2-3mm aperture with a softened light grey gouge filling. Some iron staining also. No change in schistosity.	4	1	4		65
	x				x	x	x	x		150		4		Slight broken zone along 2 jt sets (foliation parallel and perp.) at start of interval. Surfaces rough, slight iron staining. Foliation parallel jts show staining halo.	9	3	2		
Rock more broken than above. No change in rock itself. Qtz banding still variable, a few further spacedlarge bands. Still UW. Banding dies off 150.6m	x				x	x	x	x		151		10		Core parallel jt runs for 300mm, iron stained rough surface. At 150.6 jt along foliation has 20-30mm fill of light grey clay and crushed rock. Surfaces of jt smooth and micaceous.	9	1	6		
	x				x	x	x	x		152.4		6		As at 149.2 variouus breaks down this interval along foliation and some perpendicular to foliation with rough slightly silty surfaces.	9	1.5	1		52
Slightly darker grey quartzo-feldspathic/biotite schist. Qtz banding mainly gone untill 153.9 when a large qtz band flecked with biotite appears. O more are seen after this though. Rock still UW.	x				x	x	x	x		154		3		Schistosity as above, less banded. Rock still breaking along it if forced. Jt set perpendicular foliation. Surfaces rough with iron staining halos and light brown clay coating.	6		2		
	x				x	x	x	x		155.5		6		As above, foliation perpendicular jt set with iron staining, but core parallel set comes in again too, rough surface with slight iron staining.	6		1		60
Slightly darker schist, broken zone at the start but due to drilling rather than natural joints. A few random larger qtz bands.	x				x	x	x	x		157		2		Natural joints follow schistosity and have dark biotite micaceous coating on surface making surface smoother but still SR. No visible iron staining.	4	1.5	1		
Banding becoming very distinct between dark and light. A few very large qtz bands bordered with dark weathered biotite bands. Sme convoluted banding again with the qtz. Areas of qtz bands taking on a dark grey appearance (maybe not as pure as white bands)	x	x			x	x	x	x	x	158.5		8		Schistosity becoming convoluted and not nice parallel lines. Rock more indurated than previously. Jts occurring perpendicular to foliation, surfaces rough with micaceous coating but no iron staining.	9	1.5	1		70
Banding still very defined. Weathering incr. exp. In qtz bands. Biotite bands also quite weathered.	x	x			x	x	x	x		159		0		No natural jts, shistosity only defect. Schistosity incr in frequency and not so uniform, very undulating.	2	1	0.75		
Banding increases in frequency and size untill get almost flow textures at 159.3m. Weathering increases at 159.3m, primarily in micaceous layers and has caused lots of breakage of core.	x	x	x		x	x	x			160		8		Multiple joints all perpendicular to foliation, all with smooth, clay filled surfaces. 1-2mm aperture. Intact qtz bands all moderately weathered.	9	1	4		
Banding decreases andgoes back to normal with just random larger qtz bands.	x	x			x	x	x	x	x	161.1		0		No natural jts, shistosity only defect. Schistosity back to 'normal' with less frequent and less distinct banding.	2	1	0.75		95

		x	x	x	x	x	x		162	2	Joints parallel to foliation. Surfaces rough but with iron staining halos and silty brown coating.	4	1.5	2	
		x	x	x	x	x	x		163	3	Joints parallel to foliation but no iron staining visible, instead a softened light grey clay coating.	9	1	4	
	Return to light grey quartzo-feldspathic-biotite schist as above, a few prominent qtz veins variably scattered throughout. Mainly UW but slight weathering around veins and of some biotite rich areas.	x		x	x	x	x		164.1	3	Natural joints perpendicular to foliation but have rough surfaces and only slight iron staining. Schistosity relatively uniform.	4	3	1	90
	Interval has incr. weathering. Banding alsomore distinct (due to weathering?).	x	x	x	x	x			165	2	Joints cut perpendicular to foliation. Rough surface with silty/clay coating (light brown). Schistosity convoluted and more highly weathered leading to a decrease in strength.	4	3	2	
	Return to 'normal' grey quartzo-feldspathic/biotite schist. Variable qtz bands, mainly 2-3mm thick.	x		x	x	x	x		167.1	6	Joints parallel to foliation. Surfaces rough with extensive iron staining and light brown silt coating.	6	3	3	
		x		x	x	x	x		168	4	Slight broken zone at 167.4m, both on foliation and perpendicular. Surfaces R with light silty coating. Schistosity quite uniform, few large qtz bands.	9	2	1	
		x		x	x	x	x	x	169	4	Joints parallel to foliation, with iron stained halos. Smooth surfaces with light brown silt coating and weathered biotites. A few larger qtz bands in this section but they don't seem to affect strength of overall core.	4	2	3	
	As above, variable qtz bands and jointing, rock UW. A few larger (60mm thick) qtz zones.	x		x	x	x	x		169.9	6	As above, a few jts parallel to foliation but also a long core parallel set coming in near the end. Surface rough but with slight iron staining.	9	1.5	3	72
61	Schist as above. Banding highly variable, from very defined thinly banded sections to large qtz bands sections with not much other banding around.	x		x	x	x	x		172.9	5	Joints follow foliation orientation. SR surfaces with slight iron staining. Some convoluted banding sections where schistosity is not uniform.	6	1.5	1	93
		x		x	x	x	x		173.5	0	No natural joints, thinly banded foliation as above	2	1	0.75	
	Increased banding and weathering in this interval. Large qtz band (150mm) with highly weathered edges.	x	x	x	x	x	x		174.5	7	Natural joints follow foliation, closer together nearing large qtz band at 173.85m. Banding dies down and weathering decreases towards end of interval. Surfaces R, iron stained with silty coating	4	1.5	3	
	Schistosity returns to normal	x		x	x	x	x		175.7	3	Return to schistosity as above, a few natural joints follow foliation, R surfaces with brown silty coating	4	1.5	2	
	Rock mainly UW with areas of cavities in qtz-feldspar bands. Weathering increases near joint sets. Banding largely diminished, with a few areas of increased qtz concentration	x	x	x	x	x	x		177	15	Joints following foliation orientation, surfaces rough and iron stained with halos up the side of the core. Broken zone at 176.8 on long core parallel joint.	9	1.5	3	
	Banding distinct and uniform again	x		x	x	x	x		178.5	2	Joints along foliation orientation, surfaces R with light iron staining.	4	1.5	2	75
64	Increased weathering on qtz-feldspar bands, increasing cavities. Banding still quite variable.	x	x	x	x	x	x		181.3	10	Defects perpendicular to foliation, rough surfaces with slight iron staining. Widely spaced. Schistosity still closely spaced. Some joints also parallel to foliation, visible by slight irons tained halos, surfaces R with micaceous/silty coating	9	1.5	2	80
65	Schistosity as above, weathering unchanged, a few convoluted bands (not uniform schistosity) near the end of the interval.	x	x	x	x	x	x		184.2	13	2 sets, one perpendicular to foliation: R surface, slight iron staining. Parallel to foliation: SR surface with iron staining and some weathered mica. Broken zone at 182.3m at the intersection of the two jt sets.	9	1.5	2	83

												Weathering increased in surrounding rock too, and foliation more pronounced.					
	Weathering as above, schistosity very distinctly banded at start of interval, then relatively convoluted throughout.	x	x	x	x	x	x	185.5		5		Joints along foliation orientation, surfaces R with light iron staining halos around. Higher weathering on qtz bands is causing weakness in schistosity	4	1.5	2		
	Variable banding, from very distinct to a large zone of qtz to quite homogeneous looking rock.	x	x	x	x	x	x	187		10		Joints along foliation orientation, surfaces R with light iron staining and micaceous coating. Some jts cut perpendicular to foliation as well, same surface conditions.	9	1.5	3		70
	Decreased weathering, although increases around joints. Light grey quartzo-feldspathic/biotite schist as above. Banding	x		x	x	x	x	188.5		8		Joints all cutting perpendicular to foliation, R surfaces with light brown clay and slight iron staining. Weathering halos around joints affecting country rock.	4	1.5	2		
	random, distinct qtz bands vary but overall thin (2-4mm)	x	x	x	x	x	x	189.8		25		Broken zone to end of interval. Surfaces all coated in light brown clay and SR.					33
		x	x	x	x	x	x	190.5		15		Broken zone continues to 190.5					
	Banding becomes very distinct and large qtz bands are present.	x	x	x	x	x		192.5		11		Schistosity very distinct, breaking easily along weakened weathered qtz bands. Broken zone comes back in at 191, rock discing along schistosity.	9	1	2		30
69	Distinct banding continues, core still slightly weathered.	x	x	x	x	x	x	195.2		12		Very distinct schistosity creating weakness planes, core discing along schistosity. Main joint sets cuts foliation perpendicular, has R surface with iron staining. Shear at 194.6m, 20mm thick. Light grey clay guge with small angular clasts of schist within.	9	1	6		55
70	Bedding not so distinct, marbly/folded texture (gneissic?). Return to UW. Banding much less distinct and uniform in this section.	x		x	x	x	x	197.9		4		Far fewer jts in this section, perpendicular to foliation. Surfaces R with slight iron staining but no fill mainly. Slight silty coating on one joint.	4	1.5	1		85

Appendix C

C.1 Sample Photos

C.1.1 Unconfined Compressive strength Testing

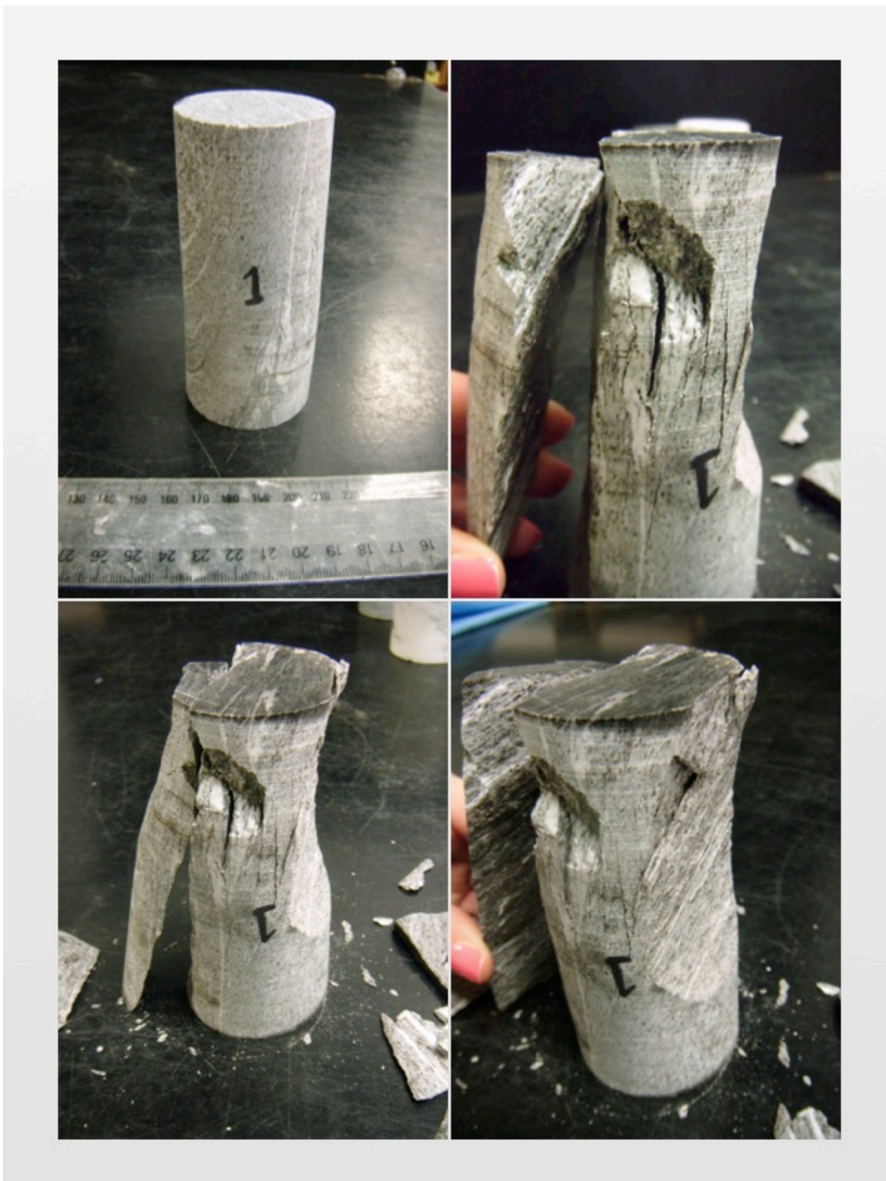


Figure C-1: Sample 1 showing failure through the sample parallel to stress direction.

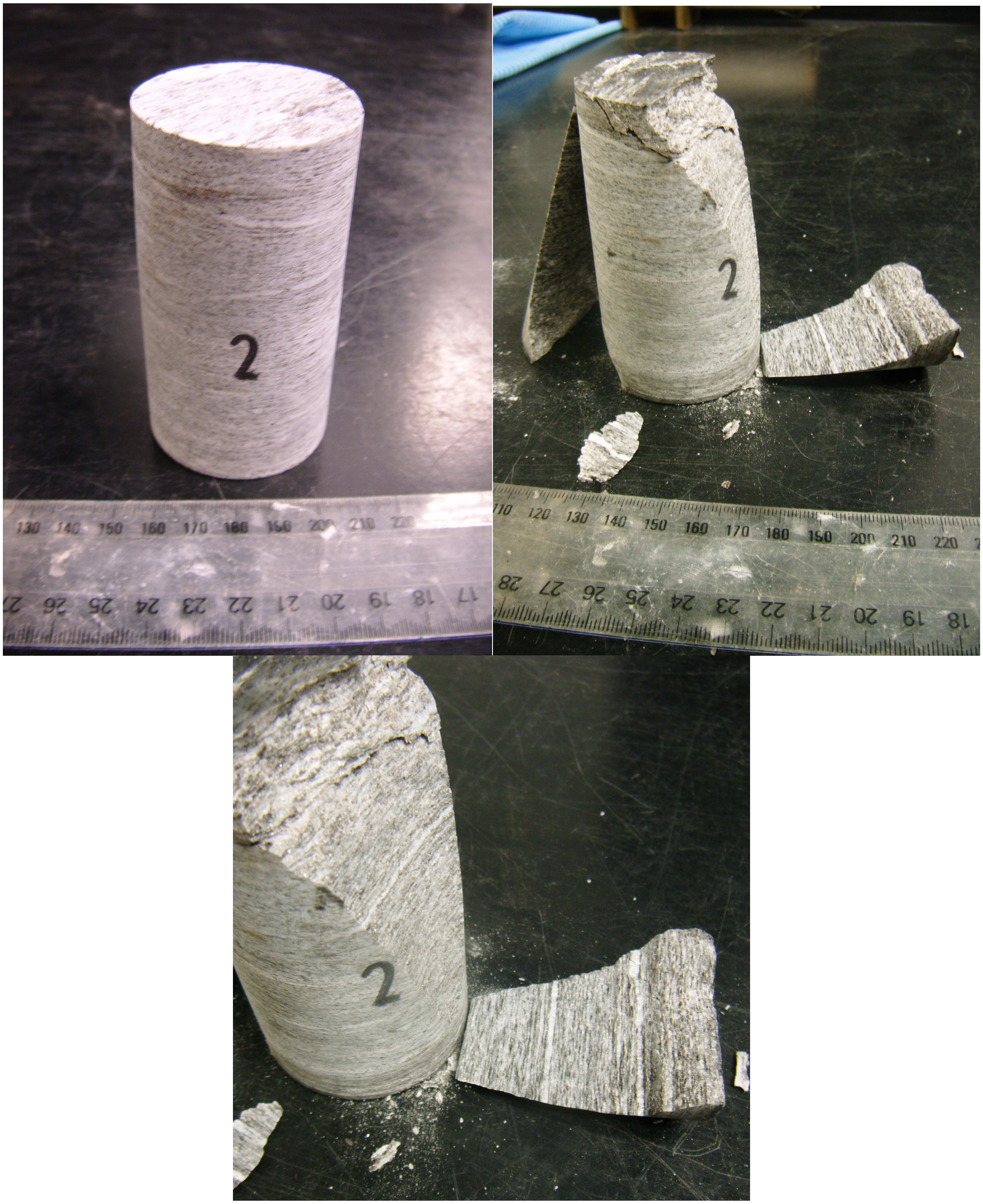


Figure C-2: Sample 2 showing failure through the intact core when tested with foliation perpendicular to stress direction.

Figure C-3: Sample 3 after testing. The sample was a large piece of quartz with little foliation. It was not representative of the overall rock mass.

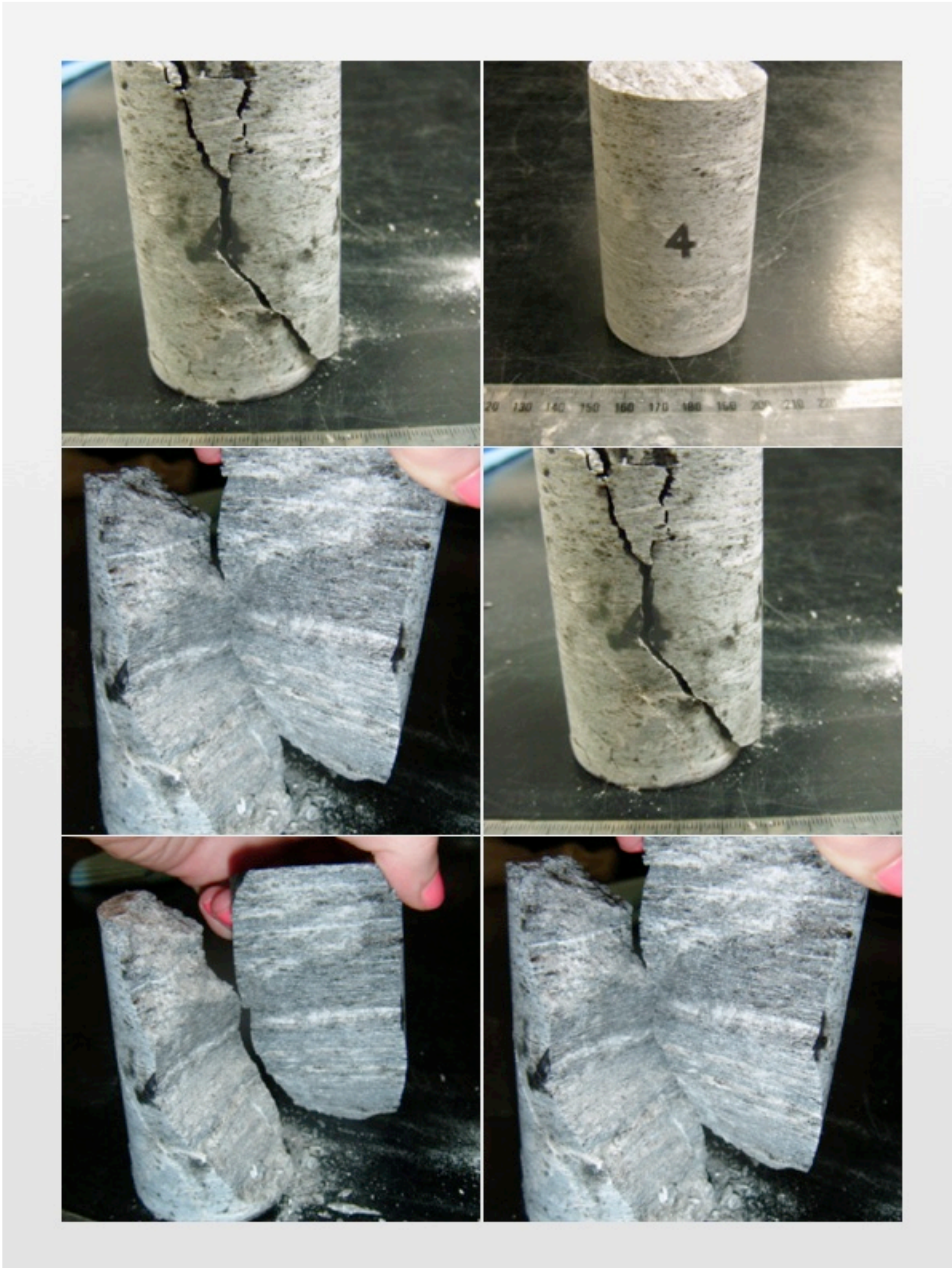


Figure C-4: Figure 4 after testing showing failure through intact core.

C.1.2 Point Load Testing

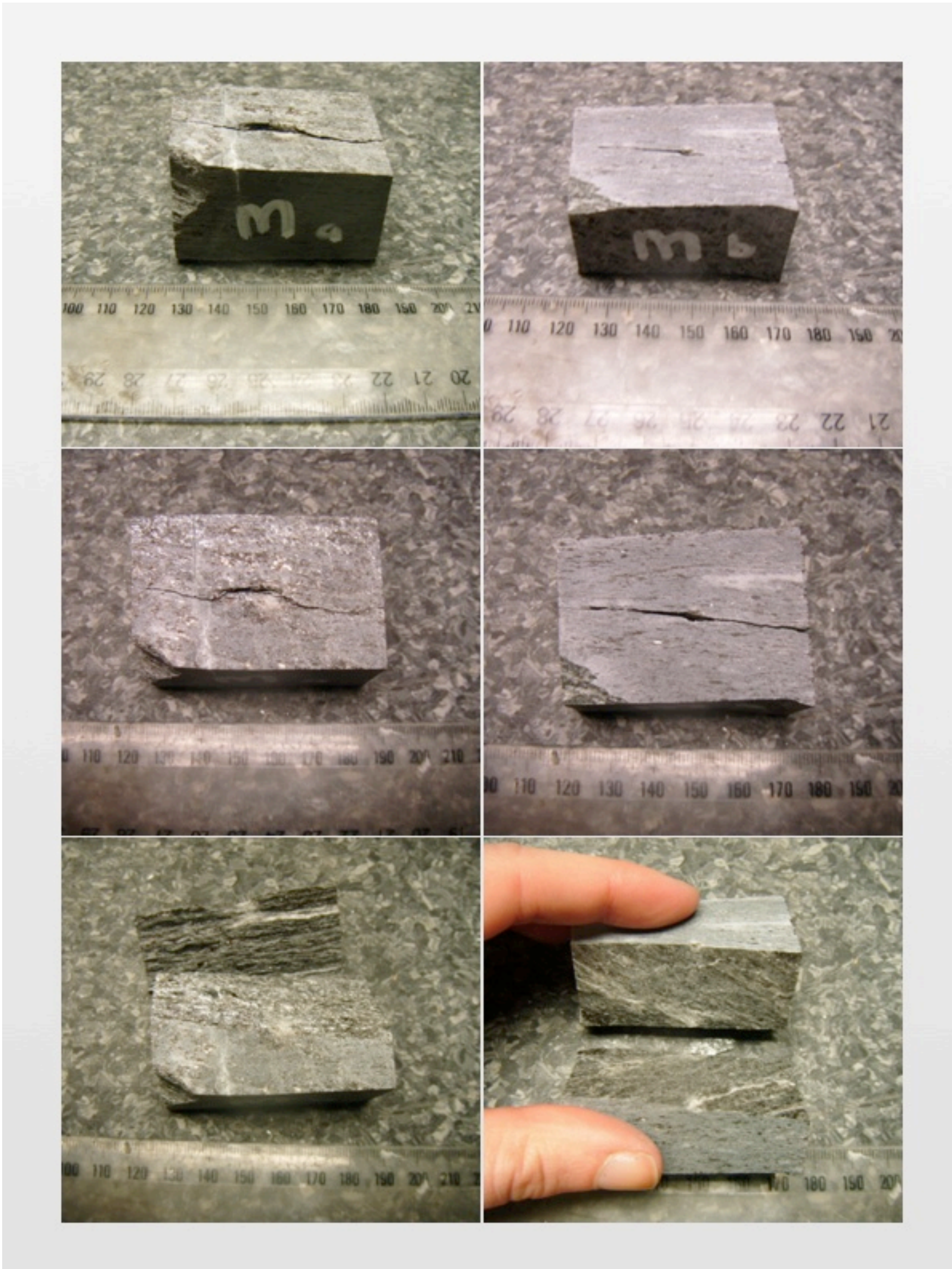


Figure C-5: Muck samples Ma and Mb after point load testing. Both tests were valid.
Figure C-6: Muck samples a and b after testing. All tests were valid.

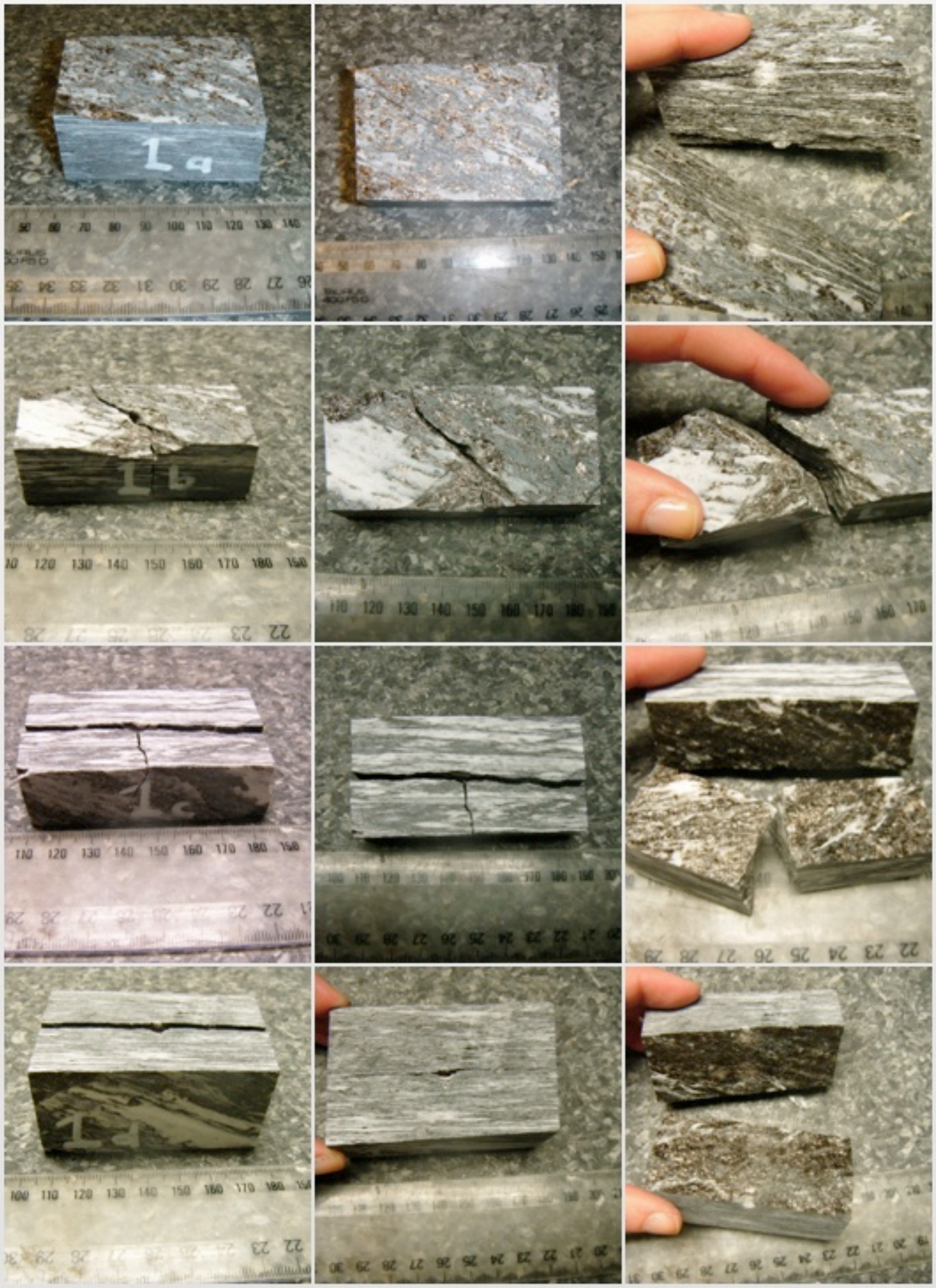


Figure C-7: Samples 1a, 1b, 1c and 1d after testing. 1b is invalid, all the rest are valid tests.

Figure C-8: Sample 2a after testing – test was invalid.

Figure C-9: Samples 3a and 3b after testing. Both samples produced the highest result for perpendicular and parallel tests respectively.

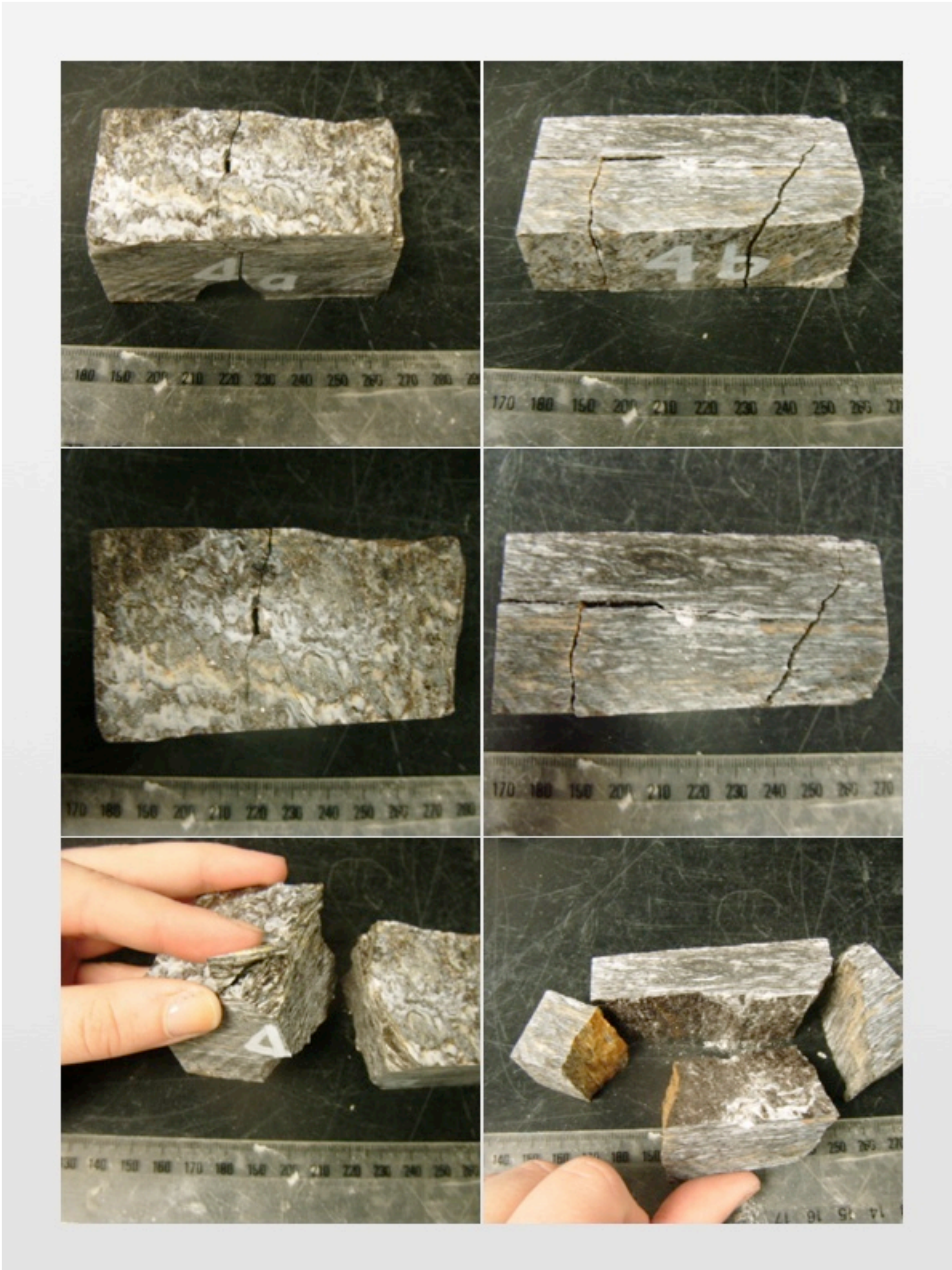


Figure C-10: Samples 4a and 4b after testing. Both tests were valid.

Figure C-11: Samples 6a, 6b and 6c after testing. Sample 6c was invalid.

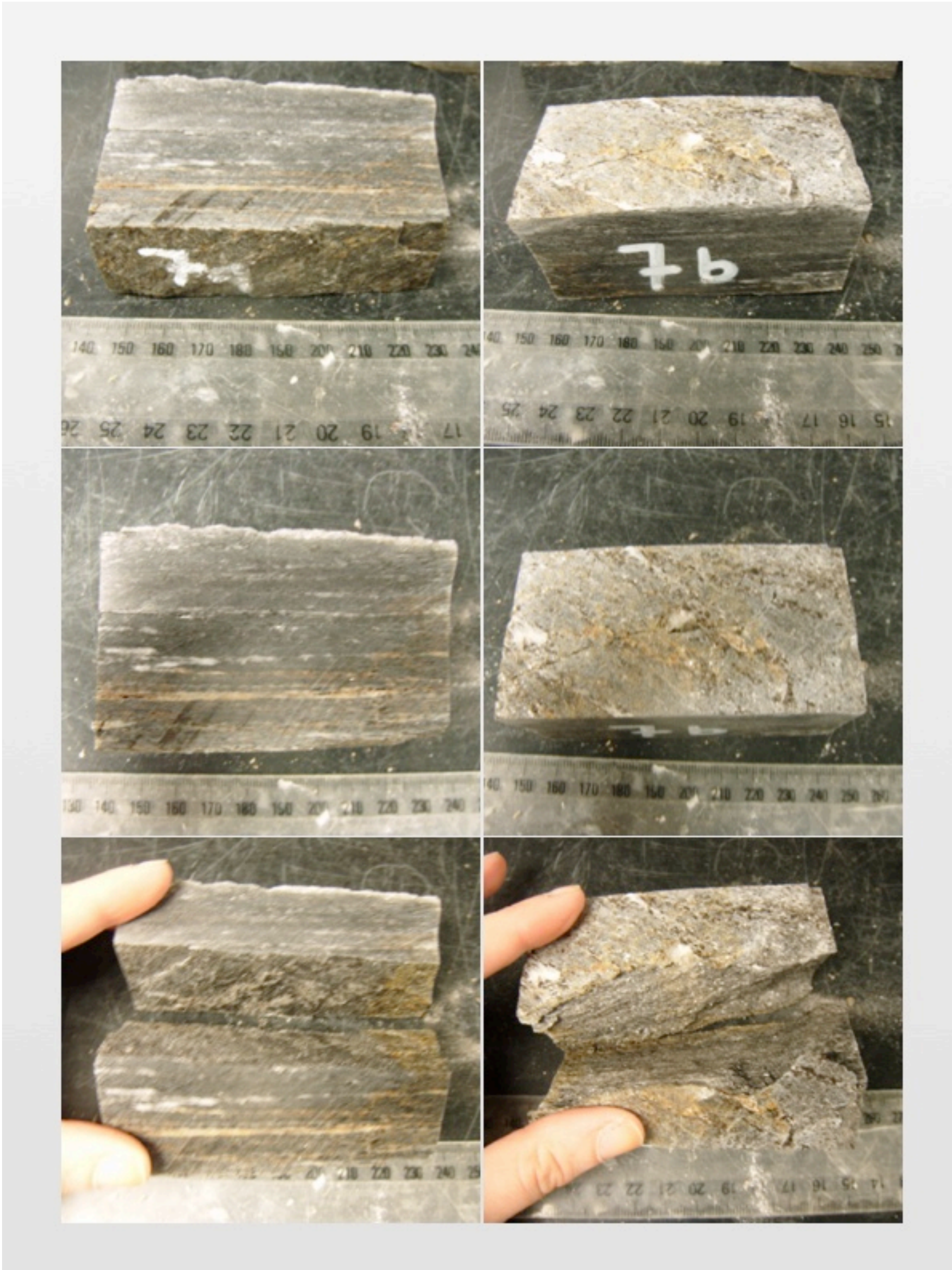


Figure C-12: Samples 7a and 7b after testing. Both samples had the lowest strength for parallel and perependicular tests respectively.

C.2 Results

C.2.1 Unconfined Compressive Strength Testing

Uniaxial Compressive Strength													
Sample ID	**Foliation Orientation relative to Stress**	**Height (mm)**	**Mass (g)**	**Diameter (mm)**	**Ratio**	**P-wave velocity**	**S-wave velocity**	**Failure Load (kN)**	**Area (mm^2)**	**Stress(MPa)**	**Edyn (Gpa) (Young's Modulus)**	**ndyn (Poisson's Ratio)**	**Dry Density**
1	Parallel	112	575.8	49.7	2.25	4162	2638	93.1	1940	48.0	42.94	0.164	2650
2	Perpendicular	92	470.6	49.7	1.85	1395	1234	112.1	1940	57.8	-2.40	-1.299	2637
3	No Foliation	92	465.1	49.7	1.85	1779	1586	78.3	1940	40.4	-5.72	-1.437	2606
4	Perpendicular	85.2	451.3	49.7	1.71	1197	1149	131.6	1940	67.8	-31.45	-5.362	2730

C.2.2 Point Load Testing

AXIAL POINT LOAD TESTING - Foliation Parallel to Stress Direction													
Date:		1-Oct-12	Note: To achieve reliable results there should be at least 10 tests per sample.										
Test No.	**Type**	**P (kN)**	**D (mm)**	**D (m)**	**W (mm)**	**A = WD (mm^2)**	**A (m2)**	**D_e^2**	**D_e**	**I_s**	**F**	**$I_{s(50)}$ (MPa)**	**Notes**
Mb	Parallel	1.32	25.6	0.026	35.56	909	0.00091	1158	34.0	1.14	0.841	0.96	
1c	Parallel	3.52	25.6	0.026	36.24	926	0.00093	1179	34.3	2.99	0.844	2.52	
1d	Parallel	4.82	35.7	0.036	45.49	1622	0.00162	2065	45.4	2.33	0.958	2.24	
3b	Parallel	7.19	37.4	0.037	43.59	1628	0.00163	2073	45.5	3.47	0.959	3.33	Highest
4b	Paral	5.75	31.5	0.031	38.91	1225	0.00123	1560	39.5	3.69	0.899	3.32	

	lel												
6a	Parallel	1.65	22.7	0.023	35.79	811	0.00081	1033	32.1	1.60	0.820	1.31	
6b	Parallel	1.56	20.4	0.020	35.11	718	0.00072	914	30.2	1.71	0.797	1.36	
7a	Parallel	0.24	31.7	0.032	55.50	1759	0.00176	2240	47.3	0.11	0.976	0.10	Lowest
											Average:	**1.95**	(Highest and Lowest Excluded)

AXIAL POINT LOAD TESTING - Foliation Perpendicular to Stress Direction

Date: 1-Oct-12

Note: To achieve reliable results there should be at least 10 tests per sample.

Test No.	Type	P (kN)	D (mm)	D (m)	W (mm)	A = WD (mm^2)	A (m2)	D_e^2	D_e	I_s	F	$I_{s(50)}$ (MPa)	Notes
Ma	Perpendicular	12.71	35.5	0.035	35.45	1257	0.00126	1601	40.0	7.94	0.905	7.18	
1a	Perpendicular	17.87	30.5	0.030	48.33	1472	0.00147	1874	43.3	9.53	0.937	8.94	
1b	Perpendicular	6.60	23.1	0.023	33.40	771	0.00077	982	31.3	6.72	0.810	5.45	Invalid
2a	Perpendicular	6.78	29.8	0.030	39.74	1183	0.00118	1506	38.8	4.50	0.892	4.02	Invalid
3a	Perpendicular	16.36	30.2	0.030	37.15	1122	0.00112	1428	37.8	11.45	0.882	10.10	Highest
4a	Perpendicular	16.52	38.2	0.038	44.97	1719	0.00172	2188	46.8	7.55	0.970	7.33	
6c	Perpendicular	8.89	32.2	0.032	44.79	1442	0.00144	1836	42.8	4.84	0.933	4.52	Invalid
7b	Perpendicular	4.23	38.3	0.038	46.64	1786	0.00179	2275	47.7	1.86	0.979	1.82	Lowest
											Average:	**6.24**	(Highest and Lowest Excluded)

Appendix D

D.1 Rmr$_{89}$

D.1.1 RMR$_{89}$ Classification Scheme

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values						
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core Quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge > 5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Groundwater	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125		
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	

D.1.2 RMR$_{89}$ observations from the Amethyst Hydro Tunnel

DATE				**16/06/12**		**16/06/12**		**16/06/12**		**16/06/12**	
DIP/DIP DIRECTION				**36/154**		**45/119**		**48/138**		**70/076**	
CHAINAGE				**123**		**130**		**145.5**		**149**	
STRENGTH		>250MPa	15								
		100-250	12								
		50-100	7	x	7	x	7	x	7	x	7
		25-50	4								
		5.0-25	2								
		0.1-5	1								
		<1	0								
RQD		<25%	3	20%	3	10%	3	10-15%	3		
		25-50%	8							25%	8
		50-75%	13								
		75-90%	17								
		90-100%	20								
JOINT SPACING		>2m	20								
		0.6-2m	15								
		200-600mm	10								
		60-200mm	8	150	8			80-100	8	100	8
		<60mm	5			50	5				
DISCONTINUITY CONDITIONS	Length	<1m	6								
		1-3m	4	2m	4					2m	4
		3-10m	2			4m	2	4m	2		
		10-20m	1								
		>20m	0								
	Aperture (mm)	None	6					0mm	6		
		<0.1mm	5								
		0.1-1.0mm	4	1mm	4					1mm	4
		1-5mm	1								
		>5mm	0			10mm	0				
	Roughness	Very rough	6								
		Rough	5	x	5	x	5			x	5
		Slightly rough	3								
		Smooth	1					x	1		
		Slickensided	0								
	Infill	None	6					x	6		
		Hard <5mm	4	x	4					x	4
		Hard >5mm	2			x	2				
		Soft <5mm	2								
		Soft >5mm	0								
	Weathering	Unweathered	6	x	6						
		Slightly weathered	5					x	5	x	5
		Moderately weathered	3			x	3				
		Highly weathered	1								
		Decomposed	0								
GROUNDWATER		Dry	15	x	15			x	15	x	15
		Damp	10								
		Wet	7								
		Dripping	4			x	4				
		Flowing	0								
ORIENTATION	Strike parallel to face	w/tunnel steep	0					x	0		
		w/tunnel shallow	-2	x	-2	x	-2				
		against steep	-5								
		against shallow	-10								
	Strike parallel to axis	Parallel steep	-12							x	-12
		Parallel shallow	-5								
		Horizontal	-5								
TOTAL				54		29		53		48	
			Rock Class	Fair		Poor		Fair		Fair	

16/06/12		**16/06/12**		**16/06/12**		**16/06/12**		**16/06/12**		**19/06/12**		**19/06/12**		**19/06/12**		**19/06/12**		**19/06/12**		**19/06/12**	
86/074		**35/128**		**50/162**		**43/130**		**30/150**		**56/156**		**60/350**		**68/150**		**88/232**		**68/288**		**50/188**	
151		**155**		**164**		**171**		**177**		**180**		**181**		**185.5**		**190**		**195**		**200**	
x	7	x	7	x	7	x	7	x	7	x	7	x	4	x	7	x	7	x	7	x	7
70	13	40%	8	40%	8	20%	3	30%	8	20%	3	20%	3	20-0%	3	40%	8	30%	8	35%	8
200	8	150	8	200	8	50	5	50	5	60	8	60	8	200	10	200	8	100	8	200	8
2m	4	5m	2	3m	2	4m	2	6m	2	4m	2	5m	2	6m	2	1.5m	4	1.5m	4	2m	4
2mm	1	2mm	1	0mm	6	0mm	6	10mm	0	0mm	6	250mm	0	30mm	0	0mm	6	0mm	6	2mm	1
x	5	x	1	x	3	x	1	x	1	x	3	x	6	x	5	x	5	x	3	x	5
x	4	x	2	x	6	x	6	x	0	x	6	x	0	x	0	x	6	x	6	x	2
x	5	x	6	x	5	x	3	x	5	x	5	x	6	x	6	x	5	x	5	x	6
x	15	x	15	x	15	x	7	x	7	x	15	x	15	x	15	x	10	x	15	x	10
		x	-2	x	0	x	-2	x	-2	x	0	x	-5	x	-5					x	0
x	-12															x	-12	x	-12		
50		48		60		38		33		55		39		43		47		50		51	
Fair		Fair		Fair		Poor		Poor		Fair		Poor		Fair		Fair		Fair		Fair	

21/06/12		21/06/12		21/06/12		21/06/12		21/06/12		21/06/12		21/06/12		21/06/12		20/06/12		20/06/12		20/06/12	
86/324		**58/295**		**60/136**		**50/298**		**24/058**		**60/300**		**45/045**		**70/135**		**70/114**		**56/176**		**72/106**	
265		**270**		**275**		**280**		**285**		**290**		**295**		**300**		**300**		**305**		**309.3**	
x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7
40%	8	35%	8	40%	8	60%	13	50%	13	70%	13	25%	3	80%	17	50%	8	70%	13	40%	8
100	8	200	8	300	10	250	10	300	10	300	10	150	8	300	10	150	8	300	10	200	8
1m	4	1m	4	4m	2	6m	2	7m	2	1m	4	5m	2	6m	2	4m	2	3m	4	4m	2
0mm	6	1mm	1	0mm	6	0mm	6	1mm	1	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6
x	3	x	1	x	1	x	3	x	1	x	5	x	1	x	5	x	5	x	6	x	6
x	6	x	4	x	6	x	6	x	2	x	6	x	6	x	6	x	6	x	6	x	6
x	5	x	5	x	5	x	5	x	5	x	5	x	5	x	3	x	3	x	6	x	5
x	10	x	10	x	7	x	10	x	10	x	15	x	4	x	7	x	7	x	7	x	10
x	-5	x	-5	x	0	x	-5			x	-5			x	0	x	0	x	0		
												x	-12							x	-12
52		43		52		57		51		66		30		63		52		65		46	
Fair		Fair		Fair		Fair		Fair		Good		Poor		Good		Fair		Good		Fair	

20/06/12		**20/06/12**		**20/06/12**		**20/06/12**		**20/06/12**		**20/06/12**		**20/06/12**		**20/06/12**		**14/06/12**		**14/06/12**		**14/06/12**	
82/084		**68/112**		**52/124**		**89/088**		**42/136**		**60/090**		**56/120**		**58/225**		**48/223**		**80/216**		**42/130**	
315		**320**		**325**		**330**		**335**		**340**		**345**		**350**		**350**		**355**		**360**	
x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7
65%	13	20%	3	40%	8	30%	8	25%	8	60%	13	25%	8	50%	13	20%	3	30%	8	20%	3
300	10	200	8	100	8	200	8	100	8	300	10	100	8	200	8	100-150	8	100-150	8	150	8
0.5	6	4m	2	4m	2	1.5	4	4m	2	3m	4	3m	4	3m	4	4m	2	3m	2	4m	2
0mm	6	0mm	6	1mm	1	0mm	6	0mm	6	2mm	1	0mm	6	0mm	6	0mm	6	0mm	6	1mm	4
x	5	x	1	x	3	x	5	x	3	x	6	x	5	x	5	x	3	x	3	x	3
x	6	x	6	x	2	x	6	x	6	x	4	x	6	x	6	x	6	x	4	x	4
x	6	x	6	x	5	x	1	x	5	x	6	x	5	x	5	x	6	x	6	x	3
x	15	x	10	x	10	x	10	x	10	x	15	x	15	x	15	x	15	x	10	x	15
		x	0	x	0			x	-2			x	0			x	0	x	0		
x	-12					x	-12			x	-12			x	-12					x	-12
62		49		46		43		53		54		64		57		56		54		37	
Good		Fair		Fair		Fair		Fair		Fair		Good		Fair		Fair		Fair		Fair	

14/06/12		20/06/12		20/06/12		20/06/12		20/06/12		20/06/12		2/07/12		2/07/12		2/07/12		2/07/12		2/07/12	
70/038		**56/120**		**50/140**		**50/136**		**52/138**		**58/090**		**62/164**		**48/158**		**54/150**		**80/056**		**68/090**	
365		**369.5**		**373.7**		**375**		**397.7**		**400**		**405**		**410**		**415**		**420**		**425**	
x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7
40%	8	60%	13	50%	13	40%	8	60%	13	20%	3	50%	8	65%	13	20%	3	60%	13	40%	8
100	8	200	8	300	10	200	8	200	8	100	8	200	8	300	10	150	8	300	10	300	10
4m	2	4m	2	4m	2	3m	2	4m	2	3m	4	5m	2	5m	2	4m	2	2m	4	5m	2
2mm	1	0mm	6	2mm	1	2mm	1	0mm	6	0mm	6	0mm	6	0.5mm	4	1mm	4	0mm	6	0mm	6
x	5	x	1	x	1	x	1	x	1	x	1	x	1	x	1	x	5	x	5	x	1
x	4	x	6	x	2	x	2	x	6	x	6	x	6	x	2	x	4	x	6	x	6
x	3	x	3	x	3	x	6	x	3	x	1	x	5	x	5	x	3	x	3	x	6
x	7	x	10	x	10	x	15	x	7	x	7	x	7	x	7	x	10	x	7	x	10
		x	0	x	0	x	0	x	0			x	0	x	0	x	0				
x	-12									x	-12							x	-12	x	-12
33		56		49		50		53		31		50		51		46		49		44	
Poor		Fair		Fair		Fair		Fair		Poor		Fair		Fair		Fair		Fair		Fair	

2/07/12		2/07/12		2/07/12		2/07/12		2/07/12		4/07/12		4/07/12		4/07/12		4/07/12		4/07/12		4/07/12	
54/310		**56/138**		**44/154**		**42/144**		**46/164**		**50/140**		**56/332**		**88/056**		**42/160**		**50/112**		**55/164**	
430		**435**		**440**		**445**		**449**		**460**		**465**		**470**		**475**		**480**		**485**	
x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7
20%	3	60%	13	60%	13	20%	3	15	3	40%	8	20%	3	20%	3	10%	3	60%	13	20%	3
100	8	100	8	200	10	100	8	100	8	100	8	100	8	100	8	<60	5	200	8	150	8
1m	4	5m	2	2.5m	4	4m	2	4m	2	5m	2	3m	2	1m	4	5m	2	5m	2	5m	2
0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6
x	5	x	3	x	1	x	1	x	1	x	1	x	5	x	5	x	1	x	1	x	3
x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	6
x	3	x	6	x	6	x	6	x	6	x	3	x	3	x	5	x	5	x	5	x	5
x	10	x	10	x	10	x	10	x	10	x	4	x	0	x	4	x	0	x	0	x	0
x	-5	x	0	x	-2	x	-2	x	0	x	0	x	-5			x	-2	x	0	x	0
														x	-12						
47		61		61		47		49		45		35		36		33		48		40	
Fair		Good		Good		Fair		Fair		Fair		Poor		Poor		Poor		Fair		Poor	

4/07/12		4/07/12		4/07/12		5/07/12		5/07/12		5/07/12		5/07/12		5/07/12		5/07/12		5/07/12		5/07/12	
57/130		**38/002**		**34/284**		**50/295**		**50/138**		**58/130**		**35/320**		**58/156**		**60/266**		**60/138**		**62/158**	
490		**495**		**500**		**505**		**510**		**515**		**520**		**525**		**530**		**533.5**		**537.1**	
x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7
60%	13	70%	13	35%	8	50%	8	80%	17	50%	8	70%	13	30%	8	70%	13	40%	8	70%	13
300	10	200	8	100	8	150	8	500	10	100	8	200	8	100	8	250	10	300	10	400	10
5m	2	2m	4	4m	2	6m	2	6m	2	6m	2	3m	2	5m	2	3m	2	6m	2	6m	2
0mm	6	0mm	6	0mm	6	1mm	1	0mm	6	0mm	6	0mm	6	0mm	6	0.5mm	4	0mm	6	0mm	6
x	1	x	5	x	1	x	5	x	1	x	1	x	5	x	1	x	5	x	1	x	5
x	6	x	6	x	6	x	2	x	6	x	6	x	6	x	6	x	4	x	6	x	6
x	5	x	3	x	5	x	6	x	5	x	3	x	5	x	3	x	5	x	6	x	5
x	4	x	4	x	7	x	7	x	7	x	10	x	7	x	10	x	10	x	7	x	10
x	0	x	-10			x	-5	x	0	x	0	x	-10	x	0			x	0	x	0
				x	-5											x	-12				
54		46		45		41		61		51		49		51		48		53		64	
Fair		Fair		Fair		Fair		Good		Fair		Fair		Fair		Fair		Fair		Good	

5/07/12		5/07/12		5/07/12		5/07/12		5/07/12		5/07/12		5/07/12		5/07/12		5/07/12		5/07/12		5/07/12	
58/140		**56/133**		**70/305**		**60/240**		**45/324**		**52/138**		**50/118**		**80/276**		**42/280**		**55/159**		**65/152**	
547.3		**550**		**555**		**560**		**565**		**570**		**575**		**580**		**583.5**		**585**		**590**	
x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7
70%	13	80%	17	80%	17	75%	13	40%	8	70%	13	60%	13	60%	13	10%	3	40%	8	70%	13
300	10	300	10	300	10	300	10	300	10	200	8	200	8	300	10	<60	5	150	8	300	10
6m	2	6m	2	2m	4	1m	4	3m	2	6m	2	6m	2	3m	2	8m	2	6m	2	6m	2
0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	1mm	1	10mm	0	1mm	1
x	5	x	1	x	5	x	1	x	3	x	1	x	1	x	5	x	3	x	1	x	1
x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	4	x	0	x	4
x	6	x	6	x	5	x	5	x	5	x	5	x	5	x	5	x	3	x	3	x	3
x	15	x	15	x	10	x	7	x	7	x	7	x	10	x	10	x	7	x	7	x	10
x	0	x	0	x	-5			x	-10	x	0	x	0					x	0	x	0
						x	-12							x	-12	x	-5				
70		70		65		47		44		55		58		52		30		36		51	
Good		Good		Good		Fair		Fair		Fair		Fair		Fair		Poor		Poor		Fair	

5/07/12		10/07/12		10/07/12		10/07/12		10/07/12		10/07/12		10/07/12		10/07/12		10/07/12		10/07/12		10/07/12	
88/038		**80/074**		**60/158**		**58/138**		**64/144**		**90/057**		**60/134**		**60/167**		**55/142**		**45/282**		**54/140**	
595		**605**		**610**		**614**		**620**		**625**		**630**		**634**		**641.4**		**645**		**650**	
x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7
30%	8	20%	3	80%	17	70%	13	60%	13	30%	8	70%	13	60%	13	60%	13	60%	13	40%	8
100	8	30	5	300	10	300	10	150	8	100	8	100	8	300	10	100	8	100	8	100	8
3m	2	4m	2	5m	2	5m	2	5m	2	2m	4	5m	2	5m	2	5m	2	4m	2	5m	2
0mm	6	5mm	1	0mm	6	0mm	6	0.2mm	4	0mm	6	1mm	1	0mm	6	0mm	6	0mm	6	0.5mm	4
x	5	x	0	x	1	x	1	x	1	x	0	x	1	x	1	x	1	x	1	x	1
x	6	x	2	x	6	x	6	x	4	x	6	x	2	x	6	x	6	x	6	x	2
x	3	x	3	x	3	x	6	x	5	x	5	x	5	x	6	x	6	x	6	x	6
x	10	x	0	x	10	x	0	x	7	x	7	x	7	x	7	x	7	x	10	x	10
				x	0	x	0	x	0			x	0	x	0	x	0			x	0
x	-12	x	-12							x	-12							x	-12		
43		11		62		51		51		39		46		58		56		47		48	
Fair		V. poor		Good		Fair		Fair		Poor		Fair		Fair		Fair		Fair		Fair	

12/07/12		12/07/12		12/07/12		12/07/12		12/07/12		12/07/12		12/07/12		12/07/12		12/07/12		12/07/12		12/07/12	
54/128		**54/288**		**58/128**		**70/065**		**60/126**		**59/150**		**55/150**		**62/125**		**60/150**		**50/140**		**60/156**	
655		**660.5**		**666**		**670**		**675**		**680**		**685**		**690**		**695**		**700**		**705**	
x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7
60%	13	60%	13	60%	13	50%	8	50%	8	20%	3	40%	8	20%	3	50%	8	70%	13	70%	13
200	8	150	8	150	8	200	8	200	8	150	8	200	8	100	8	300	10	300	10	200	8
5m	2	4m	2	5m	2	2m	4	5m	2	5m	2	6m	2	6m	2	5m	2	6m	2	5m	2
0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6
x	3	x	5	x	1	x	5	x	1	x	1	x	5	x	1	x	3	x	1	x	5
x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	6
x	6	x	6	x	6	x	5	x	5	x	5	x	3	x	5	x	5	x	3	x	5
x	10	x	10	x	10	x	10	x	7	x	10	x	10	x	10	x	4	x	4	x	0
x	0			x	0			x	0	x	0	x	0	x	0	x	0	x	0	x	0
		x	-12			x	-12														
61		51		59		47		50		48		55		48		51		52		52	
Good		Fair		Fair		Fair		Fair		Fair		Fair		Fair		Fair		Fair		Fair	

12/07/12		**12/07/12**		**12/07/12**		**12/07/12**		**12/07/12**		**12/07/12**		**12/07/12**		**12/07/12**		**19/08/12**		**19/08/12**		**19/08/12**	
50/140		**62/168**		**50/143**		**56/140**		**70/056**		**55/145**		**88/220**		**53/158**		**88/257**		**68/198**		**32/244**	
709		**715**		**720.6**		**725**		**730**		**738.3**		**740**		**751**		**755**		**760**		**765.3**	
x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7
40%	8	30%	8	20%	3	10%	3	60%	13	60%	13	60%	13	70%	13	50%	13	30%	8	30%	8
200	8	150	8	100	8	50	5	300	10	200	8	200	8	50mm	5	50mm	5	100mm	8	50mm	5
6m	2	6m	2	3m	2	5m	2	4m	2	5m	2	3m	2	6m	2	1m	4	6m	2	6m	2
0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6	0.5mm	4	40mm	0
x	3	x	1	x	6	x	5	x	1	x	1	x	5	x	3	x	1	x	3	x	1
x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	6	x	2	x	0
x	5	x	5	x	5	x	5	x	5	x	6	x	5	x	6	x	5	x	3	x	3
x	7	x	10	x	4	x	7	x	4	x	0	x	4	x	10	x	10	x	15	x	10
x	0	x	0	x	0	x	0			x	0			x	0			x	0		
								x	-12			x	-12			x	-12			x	-5
52		53		47		46		42		49		44		58		45		52		31	
Fair		Fair		Fair		Fair		Fair		Fair		Fair		Fair		Fair		Fair		Poor	

19/08/12		19/08/12		19/08/12		19/08/12		19/08/12		3/05/12		3/05/12		19/08/12		19/08/12		19/08/12		19/08/12	
51/313		27/138		50/147		78/098		52/158		54/164		54/164		65/138		50/063		74/035		65/140	
769		773.5		780		785		790		792		792		796.5		800		817		828	
x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7
40%	8	10%	3	10%	3	10%	3	10%	3	30%	8	70%	13	10%	3	50%	8	40%	8	30%	8
100mm	8	50mm	5	100mm	8	50mm	5	50mm	5	200	8	200	8	50mm	5	150mm	8	200mm	8	100mm	8
0.5m	6	6m	2	6m	2	2m	4	6m	2	6m	2	6m	2	6m	2	1m	4	1m	4	6m	2
0mm	6	2mm	1	0mm	6	0mm	6	0mm	6	10mm	0	1mm	1	10mm	0	0mm	6	0mm	6	0mm	6
x	1	x	1	x	1	x	5	x	1	x	3	x	3	x	1	x	5	x	5	x	1
x	6	x	2	x	6	x	6	x	6	x	2	x	2	x	2	x	6	x	6	x	6
x	5	x	1	x	3	x	5	x	5	x	5	x	5	x	5	x	6	x	6	x	6
x	7	x	7	x	4	x	4	x	7	x	0	x	0	x	0	x	10	x	15	x	10
x	0	x	-2	x	0			x	0	x	0	x	0	x	0					x	0
						x	-12									x	-12	x	-12		
54		27		40		33		42		35		41		25		48		53		54	
Fair		Poor		Poor		Poor		Fair		Poor		Fair		Poor		Fair		Fair		Fair	

19/08/12		**19/08/12**		**19/08/12**		**19/08/12**		**19/08/12**		**19/08/12**		**19/08/12**		**19/08/12**		**19/08/12**		**19/08/12**		**19/08/12**	
32/307		**55/258**		**68/145**		**67/137**		**60/136**		**86/257**		**70/157**		**28/236**		**89/289**		**64/139**		**60/140**	
835		**840**		**844**		**850**		**855.7**		**860**		**865**		**870**		**875**		**881**		**885**	
x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7	x	7
30%	8	60%	13	30%	8	50%	13	70%	13	50%	13	90	20	60%	13	40%	8	80%	17	80%	17
150mm	8	150	8	100	8	100	8	300	10	100	8	300	10	100	8	100	8	200	8	300	10
8m	2	3m	2	6m	2	6m	2	6m	2	1m	4	6m	2	1m	4	6m	2	6m	2	6m	2
0mm	6	0mm	6	0mm	6	0mm	6	0.1mm	4	1mm	1	0mm	6	0mm	6	0mm	6	0mm	6	0mm	6
x	5	x	5	x	1	x	1	x	1	x	5	x	1	x	5	x	5	x	1	x	1
x	6	x	6	x	6	x	6	x	4	x	4	x	6	x	6	x	6	x	6	x	6
x	5	x	6	x	5	x	6	x	6	x	3	x	5	x	5	x	1	x	3	x	5
x	7	x	7	x	7	x	4	x	7	x	7	x	4	x	0	x	0	x	0	x	7
x	-10			x	0	x	0	x	0			x	0					x	0	x	0
		x	-12							x	-12			x	-5	x	-12				
44		48		50		53		54		40		61		49		31		50		61	
Fair		Fair		Fair		Fair		Fair		Poor		Good		Fair		Poor		Fair		Good	

D.2 Q

D.2.1 Q Classification Scheme

DESCRIPTION	VALUE	NOTES
1. ROCK QUALITY DESIGNATION	***RQD***	
A. Very poor	0 - 25	1. Where *RQD* is reported or measured as $\leq$ 10 (including 0),
B. Poor	25 - 50	a nominal value of 10 is used to evaluate *Q*.
C. Fair	50 - 75	
D. Good	75 - 90	2. *RQD* intervals of 5, i.e. 100, 95, 90 etc. are sufficiently
E. Excellent	90 - 100	accurate.
2. JOINT SET NUMBER	J_n	
A. Massive, no or few joints	0.5 - 1.0	
B. One joint set	2	
C. One joint set plus random	3	
D. Two joint sets	4	
E. Two joint sets plus random	6	
F. Three joint sets	9	1. For intersections use ($3.0 \times J_n$)
G. Three joint sets plus random	12	
H. Four or more joint sets, random,	15	2. For portals use ($2.0 \times J_n$)
heavily jointed, 'sugar cube', etc.		
J. Crushed rock, earthlike	20	
3. JOINT ROUGHNESS NUMBER	J_r	
a. Rock wall contact		
b. Rock wall contact before 10 cm shear		
A. Discontinuous joints	4	
B. Rough and irregular, undulating	3	
C. Smooth undulating	2	
D. Slickensided undulating	1.5	1. Add 1.0 if the mean spacing of the relevant joint set is
E. Rough or irregular, planar	1.5	greater than 3 m.
F. Smooth, planar	1.0	
G. Slickensided, planar	0.5	2. J_r = 0.5 can be used for planar, slickensided joints having
c. No rock wall contact when sheared		lineations, provided that the lineations are oriented for
H. Zones containing clay minerals thick	1.0	minimum strength.
enough to prevent rock wall contact	(nominal)	
J. Sandy, gravely or crushed zone thick	1.0	
enough to prevent rock wall contact	(nominal)	
4. JOINT ALTERATION NUMBER	J_a	ϕr degrees (approx.)
a. Rock wall contact		
A. Tightly healed, hard, non-softening,	0.75	1. Values of ϕr, the residual friction angle,
impermeable filling		are intended as an approximate guide
B. Unaltered joint walls, surface staining only	1.0	25 - 35 — to the mineralogical properties of the
C. Slightly altered joint walls, non-softening	2.0	25 - 30 — alteration products, if present.
mineral coatings, sandy particles, clay-free		
disintegrated rock, etc.		
D. Silty-, or sandy-clay coatings, small clay-	3.0	20 - 25
fraction (non-softening)		
E. Softening or low-friction clay mineral coatings,	4.0	8 - 16
i.e. kaolinite, mica. Also chlorite, talc, gypsum		
and graphite etc., and small quantities of swelling		
clays. (Discontinuous coatings, 1 - 2 mm or less)		

4, JOINT ALTERATION NUMBER	J_a	ϕr degrees (approx.)	
b. Rock wall contact before 10 cm shear			
F. Sandy particles, clay-free, disintegrating rock etc.	4.0	25 - 30	
G. Strongly over-consolidated, non-softening clay mineral fillings (continuous < 5 mm thick)	6.0	16 - 24	
H. Medium or low over-consolidation, softening clay mineral fillings (continuous < 5 mm thick)	8.0	12 - 16	
J. Swelling clay fillings, i.e. montmorillonite, (continuous < 5 mm thick). Values of J_a depend on percent of swelling clay-size particles, and access to water.	8.0 - 12.0	6 - 12	
c. No rock wall contact when sheared			
K. Zones or bands of disintegrated or crushed	6.0		
L. rock and clay (see G, H and J for clay	8.0		
M. conditions)	8.0 - 12.0	6 - 24	
N. Zones or bands of silty- or sandy-clay, small clay fraction, non-softening	5.0		
O. Thick continuous zones or bands of clay	10.0 - 13.0		
P. & R. (see G.H and J for clay conditions)	6.0 - 24.0		
5. JOINT WATER REDUCTION	J_w	approx. water pressure (kgf/cm^2)	
A. Dry excavation or minor inflow i.e. < 5 l/m locally	1.0	< 1.0	
B. Medium inflow or pressure, occasional outwash of joint fillings	0.66	1.0 - 2.5	
C. Large inflow or high pressure in competent rock with unfilled joints	0.5	2.5 - 10.0	1. Factors C to F are crude estimates; increase J_w if drainage installed.
D. Large inflow or high pressure	0.33	2.5 - 10.0	
E. Exceptionally high inflow or pressure at blasting, decaying with time	0.2 - 0.1	> 10	2. Special problems caused by ice formation are not considered.
F. Exceptionally high inflow or pressure	0.1 - 0.05	> 10	
6. STRESS REDUCTION FACTOR		*SRF*	
a. Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated			
A. Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock any depth)		10.0	1. Reduce these values of *SRF* by 25 - 50% but only if the relevant shear zones influence do not intersect the excavation
B. Single weakness zones containing clay, or chemically dis-tegrated rock (excavation depth < 50 m)		5.0	
C. Single weakness zones containing clay, or chemically dis-tegrated rock (excavation depth > 50 m)		2.5	
D. Multiple shear zones in competent rock (clay free), loose surrounding rock (any depth)		7.5	
E. Single shear zone in competent rock (clay free). (depth of excavation < 50 m)		5.0	
F. Single shear zone in competent rock (clay free). (depth of excavation > 50 m)		2.5	
G. Loose open joints, heavily jointed or 'sugar cube', (any depth)		5.0	

DESCRIPTION			VALUE	NOTES
6. STRESS REDUCTION FACTOR			***SRF***	
b. Competent rock, rock stress problems				
	σ_c/σ_1	σ_t/σ_1		2. For strongly anisotropic virgin stress field (if measured): when $5 \leq \sigma_1/\sigma_3 \leq 10$, reduce σ_c to $0.8\sigma_c$ and σ_t to $0.8\sigma_t$. When $\sigma_1/\sigma_3 > 10$, reduce σ_c and σ_t to $0.6\sigma_c$ and $0.6\sigma_t$, where σ_c = unconfined compressive strength, and σ_t = tensile strength (point load) and σ_1 and σ_3 are the major and minor principal stresses.
H. Low stress, near surface	> 200	> 13	2.5	
J. Medium stress	200 - 10	13 - 0.66	1.0	
K. High stress, very tight structure (usually favourable to stability, may be unfavourable to wall stability)	10 - 5	0.66 - 0.33	0.5 - 2	
L. Mild rockburst (massive rock)	5 - 2.5	0.33 - 0.16	5 - 10	
M. Heavy rockburst (massive rock)	< 2.5	< 0.16	10 - 20	3. Few case records available where depth of crown below surface is less than span width. Suggest *SRF* increase from 2.5 to 5 for such cases (see H).
c. Squeezing rock, plastic flow of incompetent rock under influence of high rock pressure				
N. Mild squeezing rock pressure			5 - 10	
O. Heavy squeezing rock pressure			10 - 20	
d. Swelling rock, chemical swelling activity depending on presence of water				
P. Mild swelling rock pressure			5 - 10	
R. Heavy swelling rock pressure			10 - 15	

ADDITIONAL NOTES ON THE USE OF THESE TABLES

When making estimates of the rock mass Quality (*Q*), the following guidelines should be followed in addition to the notes listed in the tables:

1. When borehole core is unavailable, *RQD* can be estimated from the number of joints per unit volume, in which the number of joints per metre for each joint set are added. A simple relationship can be used to convert this number to *RQD* for the case of clay free rock masses: $RQD = 115 - 3.3\,J_v$ (approx.), where J_v = total number of joints per m^3 ($0 < RQD < 100$ for $35 > J_v > 4.5$).
2. The parameter J_n representing the number of joint sets will often be affected by foliation, schistosity, slaty cleavage or bedding etc. If strongly developed, these parallel 'joints' should obviously be counted as a complete joint set. However, if there are few 'joints' visible, or if only occasional breaks in the core are due to these features, then it will be more appropriate to count them as 'random' joints when evaluating J_n.
3. The parameters J_r and J_a (representing shear strength) should be relevant to the weakest significant joint set or clay filled discontinuity in the given zone. However, if the joint set or discontinuity with the minimum value of J_r/J_a is favourably oriented for stability, then a second, less favourably oriented joint set or discontinuity may sometimes be more significant, and its higher value of J_r/J_a should be used when evaluating *Q*. The value of J_r/J_a should in fact relate to the surface most likely to allow failure to initiate.
4. When a rock mass contains clay, the factor *SRF* appropriate to loosening loads should be evaluated. In such cases the strength of the intact rock is of little interest. However, when jointing is minimal and clay is completely absent, the strength of the intact rock may become the weakest link, and the stability will then depend on the ratio rock-stress/rock-strength. A strongly anisotropic stress field is unfavourable for stability and is roughly accounted for as in note 2 in the table for stress reduction factor evaluation.
5. The compressive and tensile strengths (σ_c and σ_t) of the intact rock should be evaluated in the saturated condition if this is appropriate to the present and future in situ conditions. A very conservative estimate of the strength should be made for those rocks that deteriorate when exposed to moist or saturated conditions.

D.2.2 Q observations from the Amethyst Hydro Tunnel

DATE				16/06/12	16/06/12	16/06/12	16/06/12
DIP/DIP DIRECTION				36/154	45/119	48/138	70/076
CHAINAGE				123	130	145.5	149
RQD		<25%	RQD%	20	10	15	
		25-50%					25
		50-75%					
		75-90%					
		90-100%					
JOINT SET NUMBER (JN)		Massive	0.5-1				
		1	2				
		1+	3	3	3	3	3
		2	4				
		2+	6				
		3	9				
		3+	12				
		4+ (heavy)	15				
		Crush	20				
JOINT ROUGHNESS (JR)	Rockwall contact/Contact before 10cm	Non-continuous joint	4				
		Rough, undulating	3				
		Smooth, undulating	2			2	
		Slickensided, undulating	1.5				
		Rough, flat	1.5	1.5	1.5		1.5
		Smooth, flat	1				
		Slickensided, flat	0.5				
	No Contact	Clay filling	1				
		Sand/gravel filling	1				
JOINT ALTERATION (JA)	Rockwall Contact	Fill dense, impermeable	0.75				
		Surface only stained	1				
		Sides slightly varied, unsoftened, sandy	2			2	
		Silty/sandy clay surface	3				
		Softened clay mineral surface	4				
	Contact before 10cm	Sandy, clay free, loose rock	4		4		
		Unsoftened (continuous, <5mm)	6	6			6
		Softened, clay fill (continuous, <5mm)	8				
		Swelling filling (continuous, <5mm)	8.0-12.0				
	Thick Filling	Crushed rock/clay	6.0; 8.0; or 8-12				
		Silty/sandy (non-softening)	5				
		Thick continuous clay zones	10; 13; or 13-20				
JOINT WATER (JW)		Dry - up to 5l/min	1	1		1	1
		Medium flow	0.66		0.66		
		Large flow - unfilled joints	0.5				
		Large flow - on joints	0.33				
		Exceptional flow - on blasting, reduces with time	0.2-0.1				
		Exceptional flow - no reduction with time	0.1-0.05				
SRF		Low stress, near surface, open joints	2.5				
		Med. Stress, favourable conditions	1	1	1	1	1
		High stress	0.5-2				
TOTAL				1.67	0.83	5.00	2.08
Q=(RQD/Jn).(Jr/Ja).(Jw/SRF)			**Rock Class**	Poor	Very Poor	Fair	Fair

16/06/12	16/06/12	16/06/12	16/06/12	19/06/12	19/06/12	19/06/12	19/06/12	19/06/12	16/06/12	18/07/11
35/128	50/162	43/130	30/150	56/156	60/350	68/150	88/232	68/288	50/188	Sarah
155	164	171	177	180	181	185.5	190	195	200	214
35	40	20	30	20	20	20	40	30	35	20
3	12	4	6	6	6	12	9	12	6	12
1	1.5	2	2	1.5	1.5	1.5	1.5	1.5	1.5	2
	1	2		1			1	1		3
8			8		8	8			8	
1	1	0.66	0.66	0.33	1	1	0.66	1	0.66	0.33
1	1	1	1	1	1	1	1	1	1	1
1.46	5.00	3.30	0.83	1.65	0.63	0.31	4.40	3.75	0.72	0.37
Fair	Fair	Fair	Very Poor	Poor	Very Poor	Very Poor	Fair	Poor	Very Poor	Very Poor

27/07/11	21/06/12	21/06/12	21/06/12	21/06/12	21/06/12	21/06/12	21/06/12	21/06/12	20/06/12	20/06/12
Sarah	86/324	58/295	60/136	50/298	24/058	60/300	45/045	50/295	70/114	56/176
224	265	270	275	280	285	290	295	300	300	305
25	40	35	40	60	50	70	25	80	50	70
12	9	6	6	12	6	6	12	6	6	12
2	1	1	1	1.5	1	3	1	1.5	1.5	3
	1	2	1	1		1	1	1	1	0.75
6					8					
0.33	0.66	0.66	0.66	0.66	0.66	1	0.66	0.66	0.66	0.66
1	1	1	1	1	1	1	1	1	1	1
0.23	2.93	1.93	4.40	4.95	0.69	35.00	1.38	13.20	8.25	15.40
Very Poor	Poor	Poor	Fair	Fair	Very Poor	Good	Poor	Good	Fair	Good

20/06/12	20/06/12	20/06/12	20/06/12	20/06/12	20/06/12	20/06/12	20/06/12	20/06/12	14/06/12	14/06/12
72/106	82/084	68/112	52/124	89/088	42/136	60/090	56/120	58/225	48/223	80/216
309.3	315	320	325	330	335	340	345	350	350	355
40	65	20	40	30	25	60	25	50	20	25
12	12	3	12	9	9	12	3	6	6	12
1.5	3	1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
1	0.75	0.75	4	0.75	0.75	0.75	1	1	1	0.75
1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1
5.00	21.67	8.89	1.25	6.67	5.56	10.00	12.50	12.50	5.00	4.17
Fair	Good	Fair	Poor	Fair	Fair	Fair	Good	Good	Fair	Fair

14/06/12	14/06/12	20/06/12	20/06/12	20/06/12	20/06/12	2/07/12	2/07/12	2/07/12	2/07/12	2/07/12
42/130	70/038	56/120	50/136	52/138	58/090	62/164	48/158	54/150	80/056	68/090
360	365	369.5	375	397.7	400	405	410	415	420	425
20	40	60	40	60	20	50	65	20	60	40
9	6	12	6	4	4	9	6	4	9	9
1	1.5	1	1	1	1	1	1	1.5	3	2
2		1		1	2	1	4		2	0.75
	6		8					4		
1	1	1	1	0.66	0.66	0.66	0.66	1	0.66	1
1	1	1	1	1	1	1	1	1	1	1
1.11	1.67	5.00	0.83	9.90	1.65	3.67	1.79	1.88	6.60	11.85
Poor	Poor	Fair	Very Poor	Fair	Poor	Poor	Poor	Poor	Fair	Good

2/07/12	2/07/12	2/07/12	2/07/12	2/07/12	4/07/12	4/07/12	4/07/12	4/07/12	4/07/12	4/07/12
54/310	56/138	44/154	42/144	46/164	50/140	56/332	88/056	42/160	50/112	55/164
430	435	440	445	449	460	465	470	475	480	485
20	60	60	20	15	40	20	20	10	60	20
4	4	4	4	6	6	9	6	3	6	4
1.5	1.5	1	1	1	1	1.5	1.5	1	1	1.5
0.75	0.75	0.75	0.75	0.75	1	1	1	1	2	1
1	1	1	1	1	0.5	0.33	0.5	0.33	0.33	0.33
1	1	1	1	1	1	1	1	1	1	1
10.00	30.00	20.00	6.67	3.33	3.33	1.10	2.50	1.10	1.65	2.48
Fair	Good	Good	Fair	Poor	Poor	Poor	Poor	Poor	Poor	Poor

4/07/12	4/07/12	4/07/12	5/07/12	5/07/12	5/07/12	5/07/12	5/07/12	5/07/12	5/07/12	5/07/12
57/130	38/002	34/284	50/295	50/138	58/130	35/320	58/156	60/266	60/138	62/158
490	495	500	505	510	515	520	525	530	533.5	537.1
60	70	35	50	80	50	70	30	70	40	70
6	9	4	6	4	3	9	9	12	4	6
1	1.5	2	1.5	1	1	1.5	2	3	1	1.5
1	0.75	1	3	1	1	1	0.75	3	1	1
0.5	0.5	0.66	0.66	0.66	1	0.66	1	1	0.66	1
1	1	1	1	1	1	1	1	1	1	1
5.00	7.78	11.55	2.75	13.20	16.67	7.70	8.89	5.83	6.60	17.50
Fair	Fair	Fair	Poor	Good	Good	Fair	Fair	Fair	Fair	Good

5/07/12	5/07/12	5/07/12	5/07/12	5/07/12	5/07/12	5/07/12	5/07/12	5/07/12	5/07/12	5/07/12
58/140	56/133	60/240	45/324	52/138	50/118	80/276	42/280	55/159	65/152	88/038
545	550	560	565	570	575	580	583.5	585	590	595
70	80	75	40	70	60	60	10	40	70	30
4	9	6	12	12	9	12	9	4	12	12
1.5	1	1	3	1	1	1.5	1.5	1	1	1.5
1	1	0.75	0.75	0.75	0.75	1	2		2	
								8		8
1	1	0.66	0.66	0.66	1	1	0.66	0.66	1	1
1	1	1	1	1	1	1	1	1	1	1
26.25	8.89	11.00	8.80	5.13	8.89	7.50	0.55	0.83	2.92	0.47
Good	Fair	Good	Fair	Fair	Fair	Fair	Very Poor	Very Poor	Poor	Very Poor

10/07/12	10/07/12	10/07/12	10/07/12	10/07/12	10/07/12	10/07/12	10/07/12	10/07/12	10/07/12	12/07/12
80/074	60/158	58/138	64/144	90/057	60/134	60/167	55/142	45/282	54/140	54/128
605	610	614	620	625	630	634	641.4	645	650	655
20	80	70	60	30	70	60	60	60	40	60
9	9	4	12	9	12	4	4	4	4	4
0.5	1	1	1	0.5	1	1	1	1	1	1.5
	2	0.75	2	0.75	4	0.75	0.75	0.75	4	1
8										
0.33	1	0.33	0.66	0.66	0.66	0.66	0.66	1	1	1
1	1	1	1	1	1	1	1	1	1	1
0.05	4.44	7.70	1.65	1.47	0.96	13.20	13.20	20.00	2.50	22.50
Ext. poor	Fair	Fair	Poor	Poor	Very poor	Good	Good	Good	Poor	Good

12/07/12	12/07/12	12/07/12	12/07/12	12/07/12	12/07/12	12/07/12	12/07/12	12/07/12	12/07/12	12/07/12
54/288	58/128	70/065	60/126	59/150	55/150	62/125	60/150	50/140	60/156	50/140
660.5	666	670	675	680	685	690	695	700	705	709
60	60	50	50	20	40	20	50	70	70	40
9	4	4	9	4	9	4	4	4	4	4
3	1	3	2	1	1.5	1	1.5	1	1.5	1.5
1	1	1	1	1	1	1	1	1	1	1
1	1	1	0.66	1	1	1	0.5	0.5	0.33	0.66
1	1	1	1	1	1	1	1	1	1	1
20.00	15.00	37.50	7.33	5.00	6.67	5.00	9.38	8.75	8.66	9.90
Good	Good	Good	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair

12/07/12	12/07/12	12/07/12	12/07/12	12/07/12	12/07/12	19/08/12	19/08/12	19/08/12	19/08/12	19/08/12
62/168	50/143	56/140	70/056	55/145	88/220	53/158	88/257	68/198	32/244	51/313
715	720.6	725	730	738.3	740	751	755	760	765	769
30	20	10	60	60	60	70	50	30	30	40
4	9	4	9	4	4	6	12	9	4	4
1	1.5	1.5	1	1	1.5	1.5	1	3	1	1
1	1	1	1	0.75	2	0.75	1			0.75
								8		
									8	
1 0.5	0.5	0.66	0.5	0.33	0.5	1	1	1	1	0.66
1	1	1	1	1	1	1	1	1	1	1
7.50	1.67	2.48	3.33	6.60	5.63	23.33	4.17	1.25	0.94	8.80
Fair	Poor	Poor	Poor	Fair	Fair	Good	Fair	Poor	Very Poor	Fair

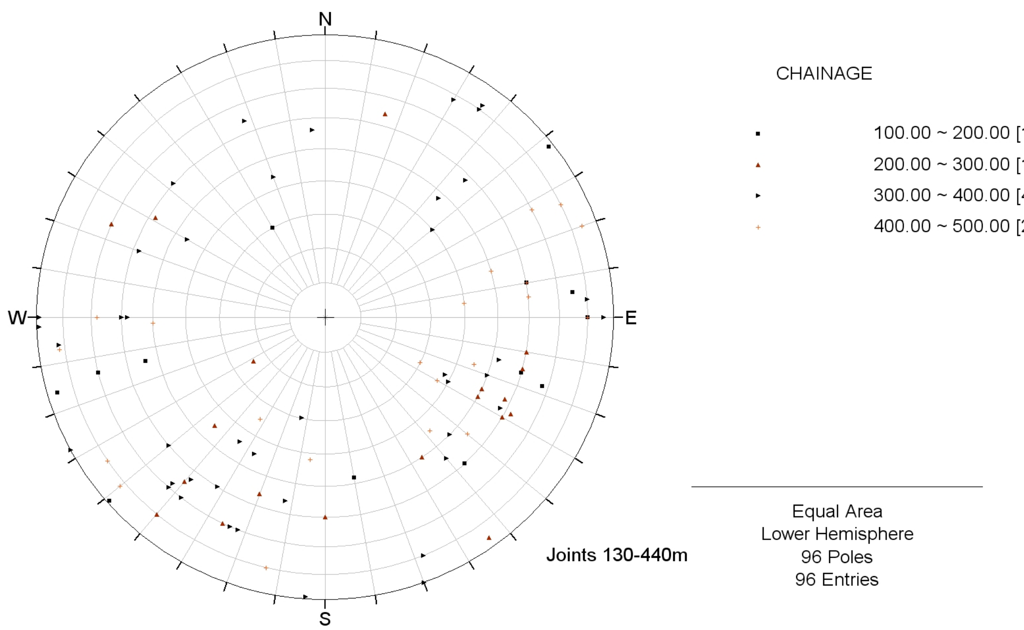
19/08/12	19/08/12	19/08/12	19/08/12	19/08/12	19/08/12	19/08/12	19/08/12	19/08/12	19/08/12	19/08/12
27/138	50/147	78/098	52/158	65/138	50/063	74/035	65/140	65/140	32/307	65/144
773.5	780	785	790	796.5	800	817	820	830	835	840
10	10	10	10	10	50	40	30	20	30	60
4	4	4	3	2	4	4	3	3	3	4
2	1	1.5	1	1	3	1.5	1	1	1.5	1
	0.75	1	1	1	1	1	0.75	0.75	1	0.75
8										
0.66	0.66	0.5	0.66	0.5	1	1	1	0.66	0.66	0.66
1	1	1	1	1	1	1	1	1	1	1
0.41	2.20	1.88	2.20	2.50	37.50	15.00	13.33	5.87	9.90	13.20
Very Poor	Poor	Poor	Poor	Poor	Good	Good	Good	Fair	Fair	Good

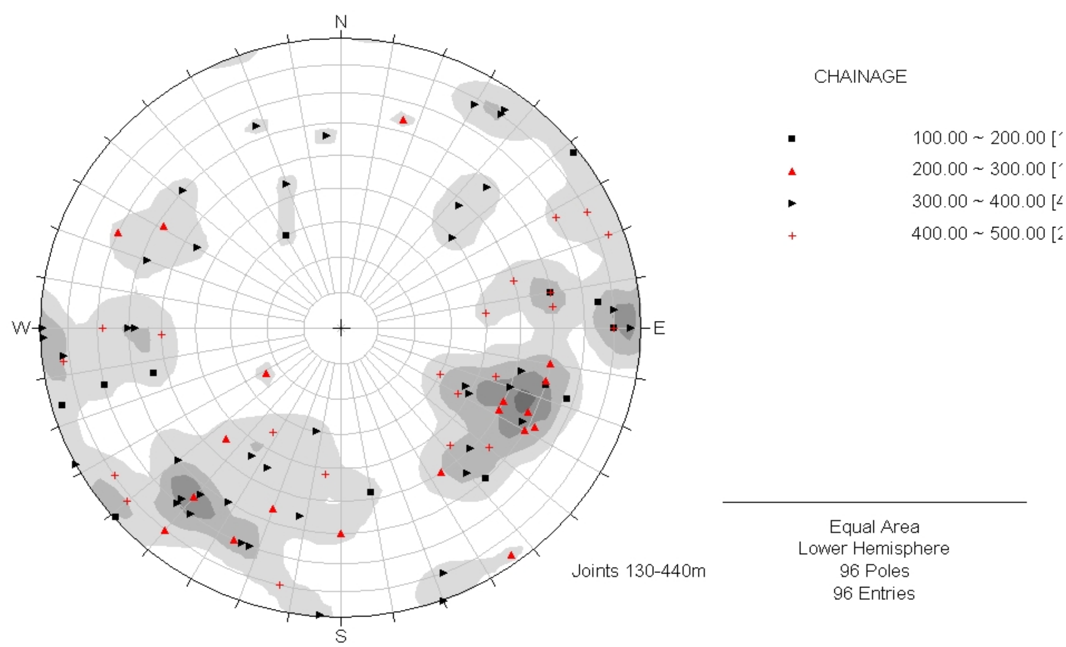
19/08/12	19/08/12	19/08/12	19/08/12	19/08/12	19/08/12	19/08/12	19/08/12	19/08/12
68/145	67/137	60/136	86/257	70/157	28/236	89/289	64/139	60/140
844	850	855.7	860	865	870	875	881	885
30	50	70	50	90	60	40	80	80
4	3	4	9	3	9	9	3	4
1	1	1	3	1	3	1.5	1	1
0.75	0.75	3	3	0.75	0.75	2	1	1
1	0.66	0.66	0.66	0.66	0.5	0.33	0.5	0.66
1	1	1	1	1	1	1	1	1
10.00	14.67	3.85	3.67	26.40	13.33	1.10	13.33	13.20
Fair	Good	Poor	Poor	Good	Good	Poor	Fair	Good

Appendix E

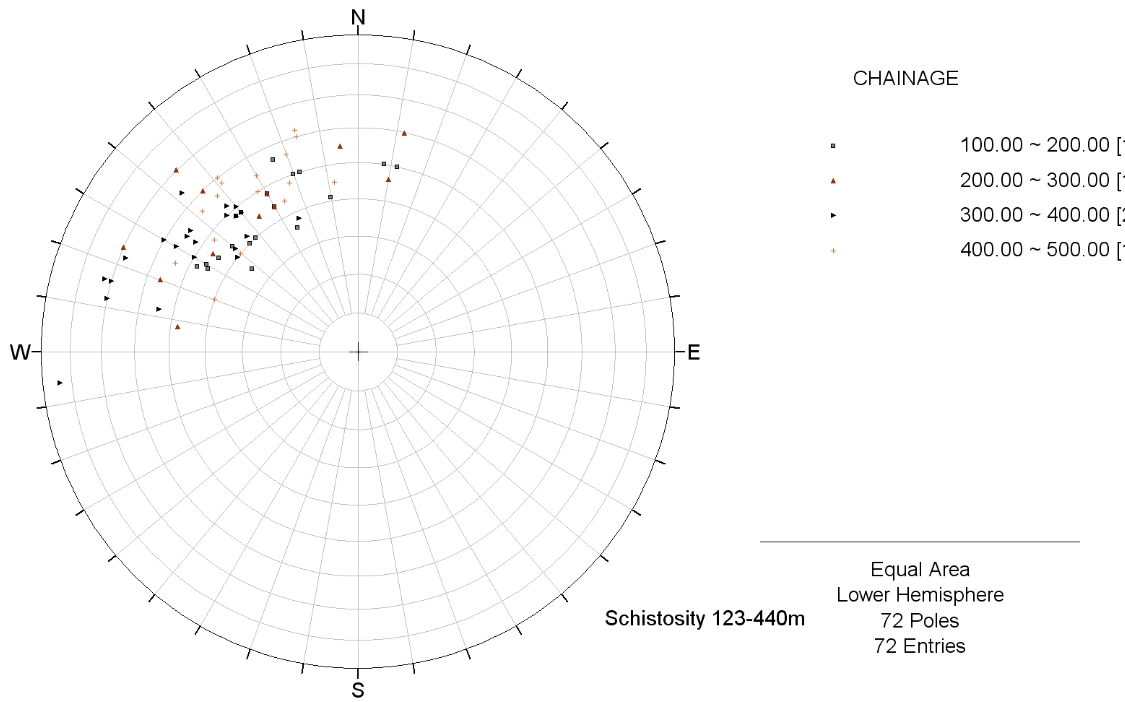
E.1 Structural Domain Classification

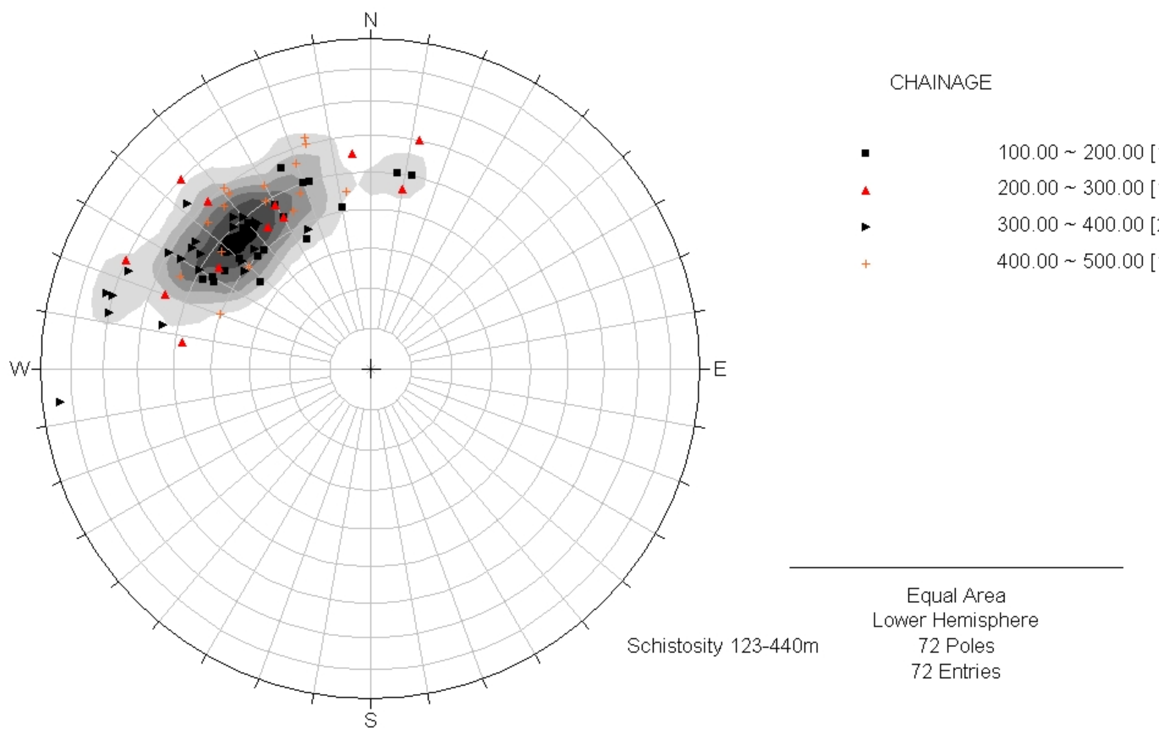
Project: Amethyst Hydro Project	**Domain:** 2
Major Structure Type: Joints	



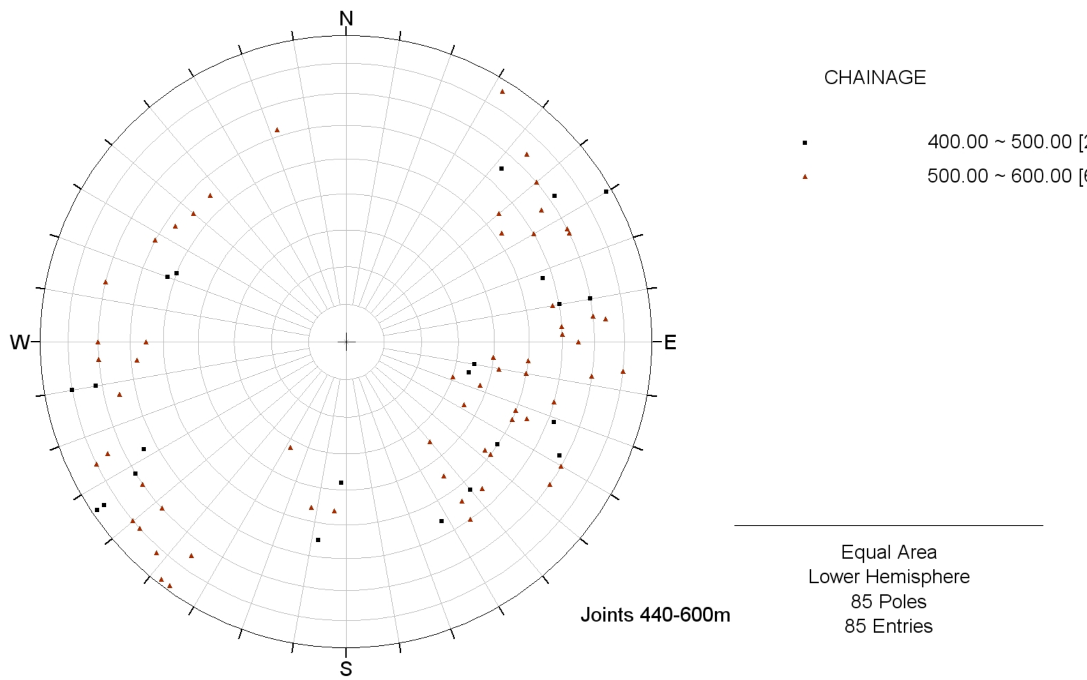


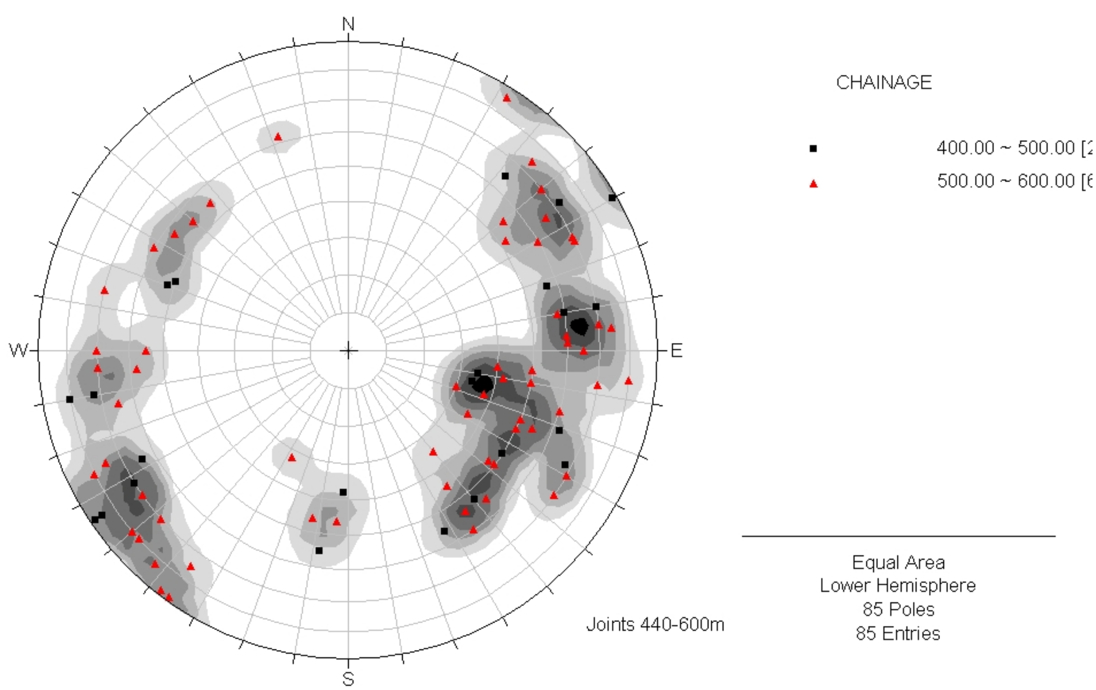
Project: Amethyst Hydro Project	**Domain:** 2
Major Structure Type: Schistosity	



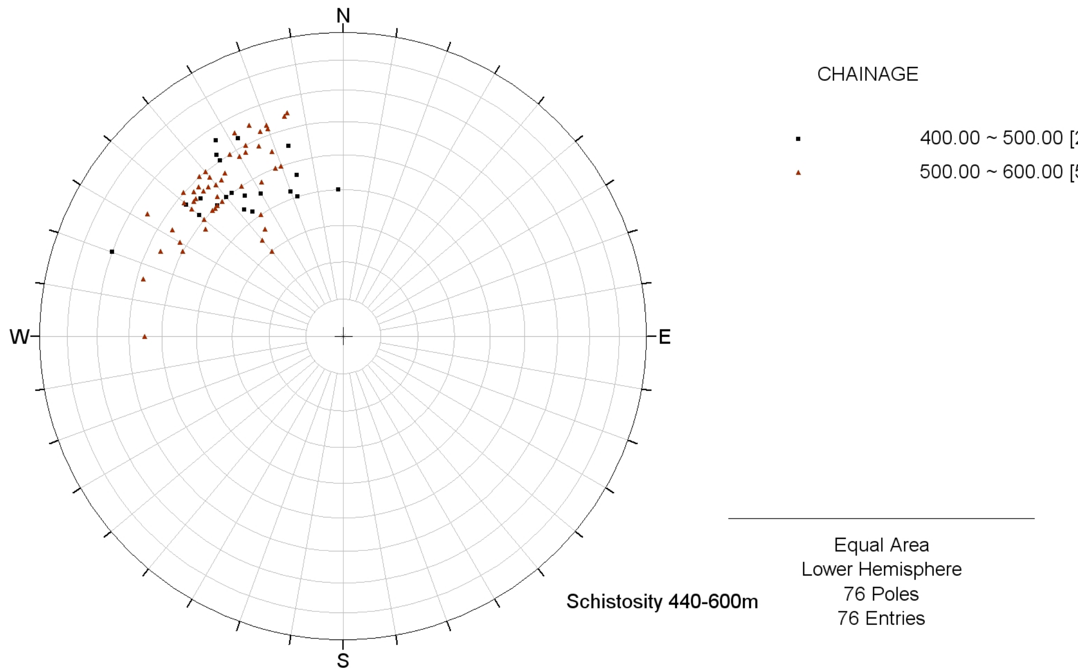


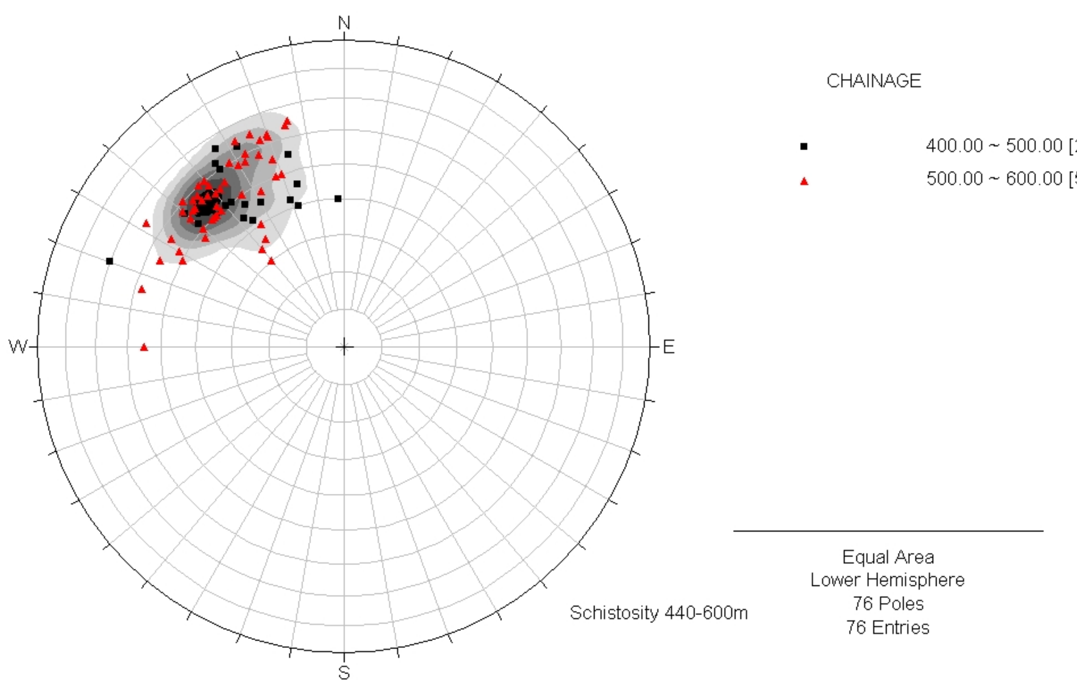
Project: Amethyst Hydro Project	Domain: 3
Major Structure Type: Joints	



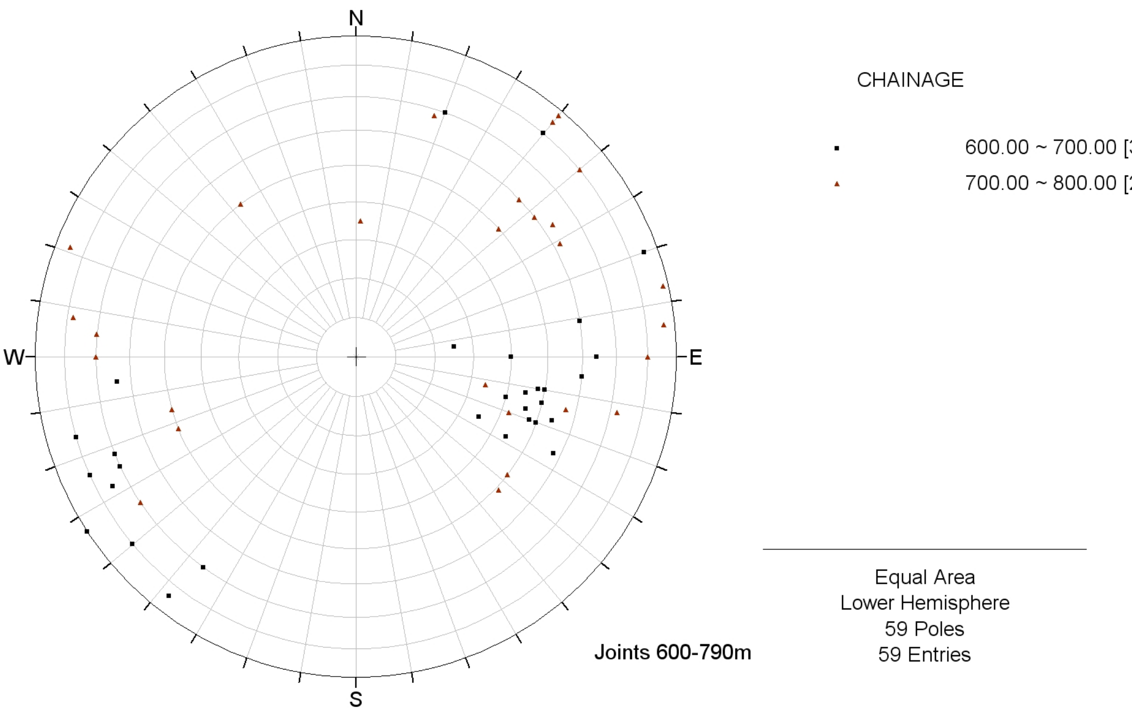


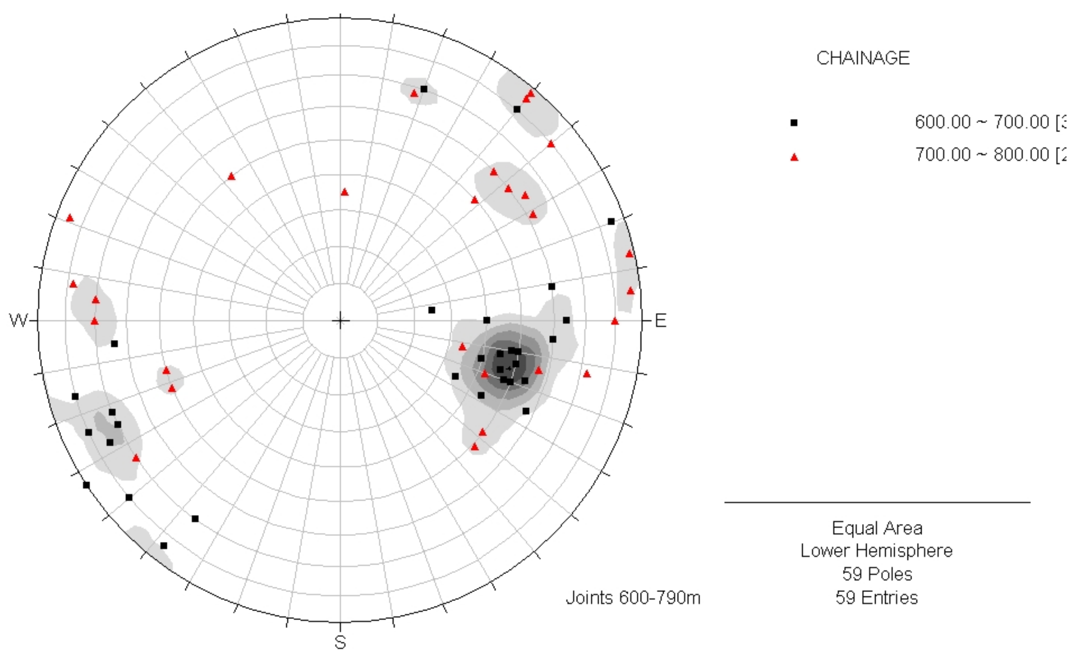
Project: Amethyst Hydro Project	**Domain:** 3
Major Structure Type: Schistosity	



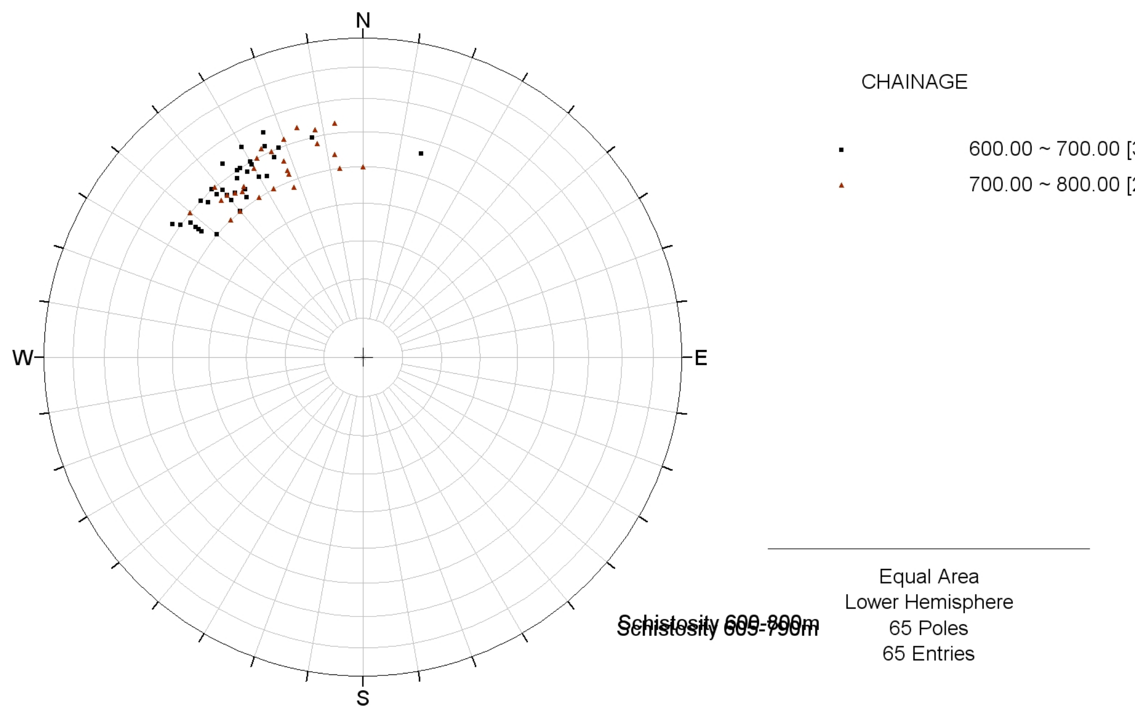


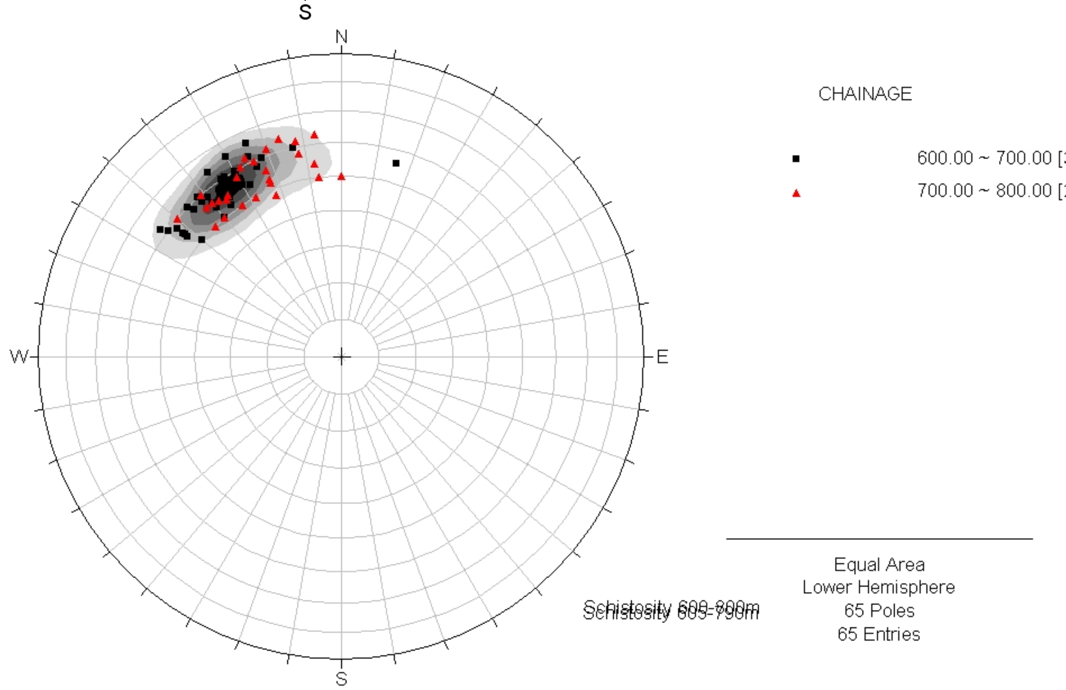
Project: Amethyst Hydro Project	Domain: 4
Major Structure Type: Joints	



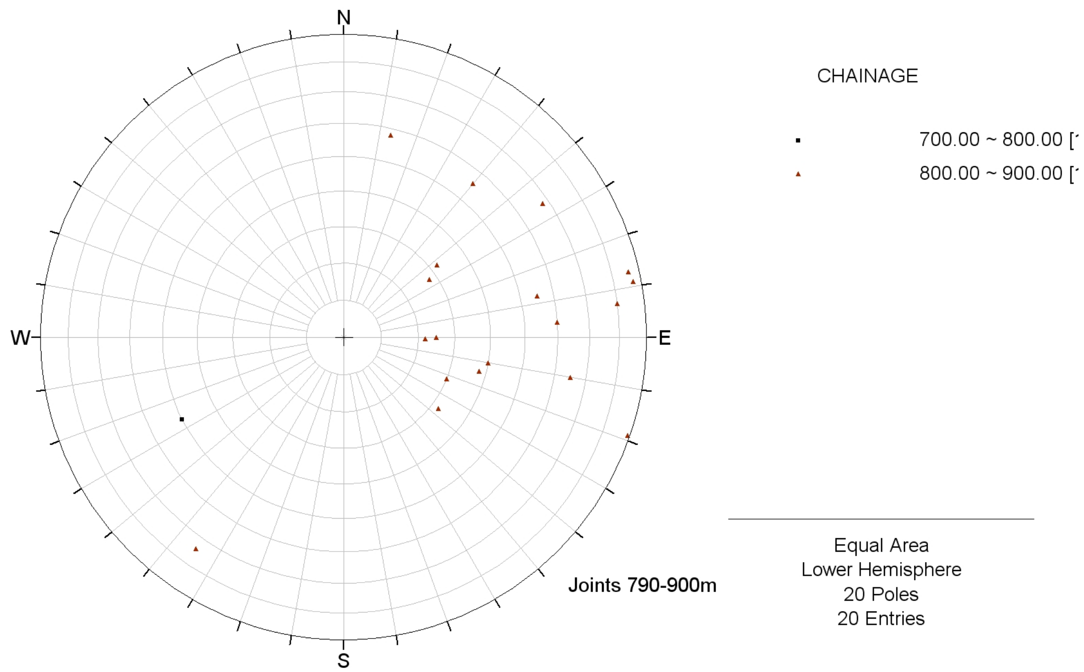


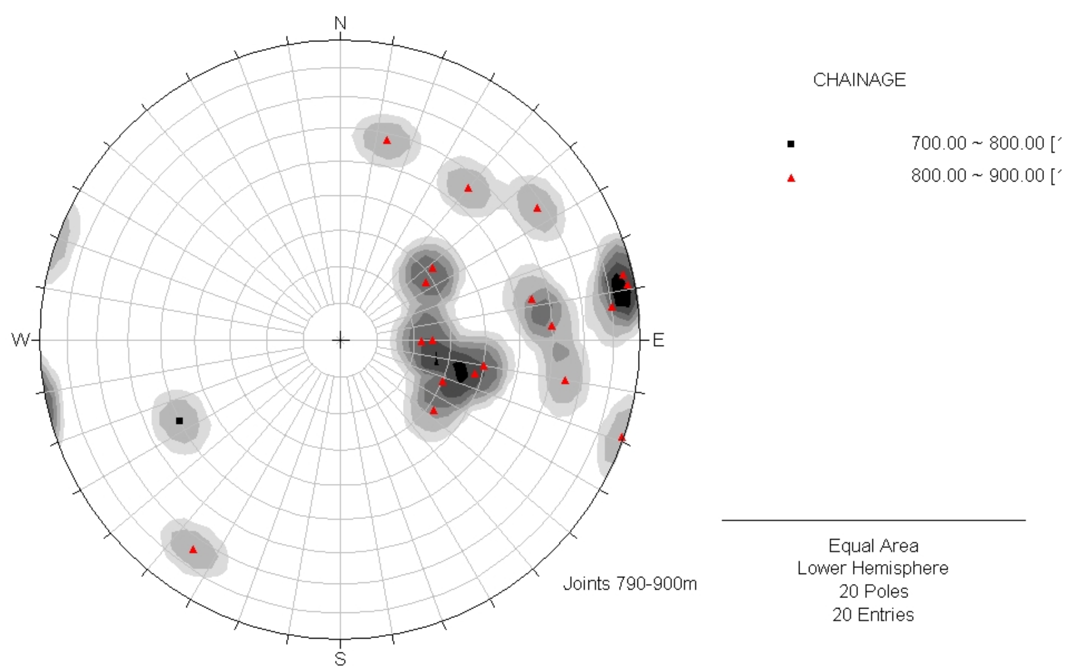
Project:	Amethyst Hydro Project	**Domain:**	4
Major Structure Type:	Schistosity		



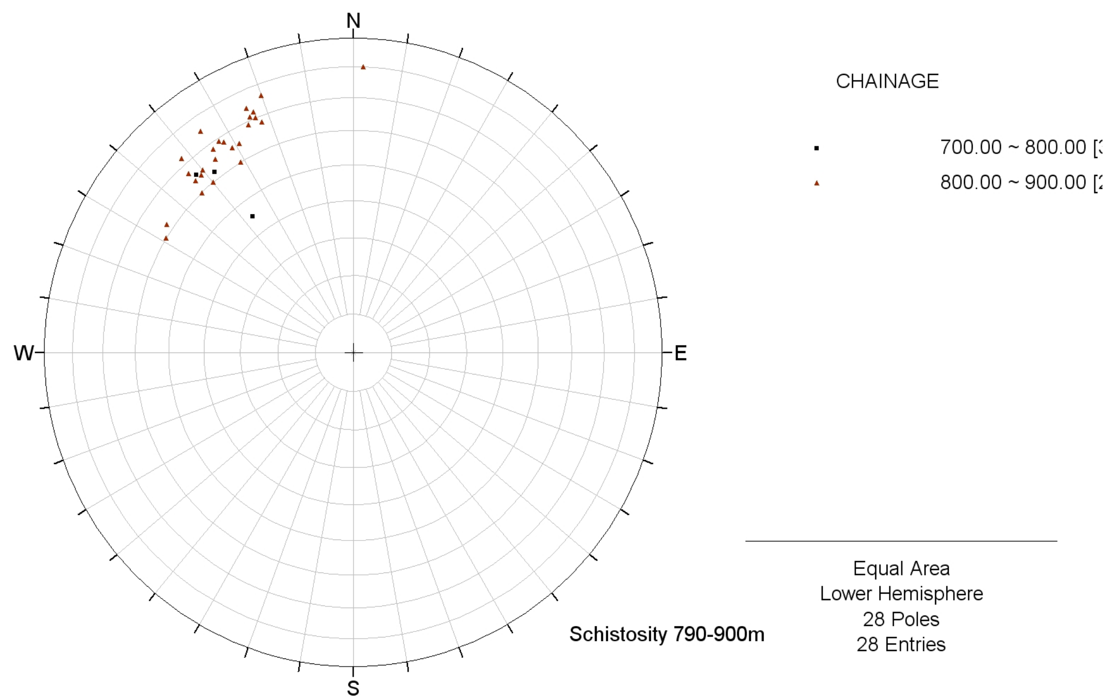


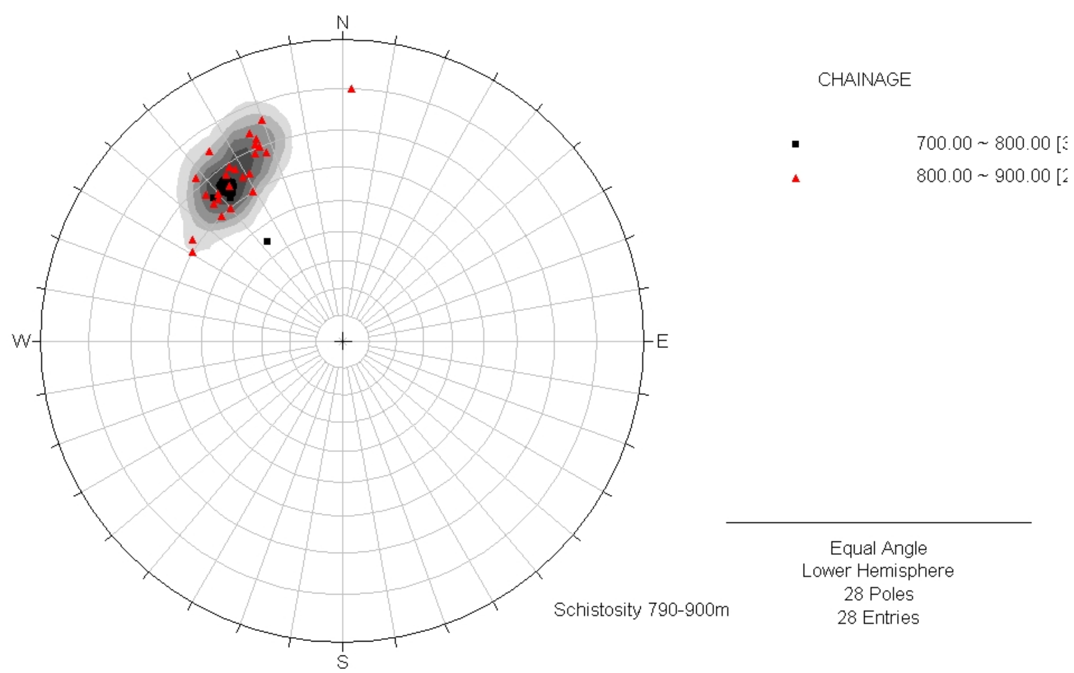
Project: Amethyst Hydro Project	**Domain:** 5
Major Structure Type: Joints	



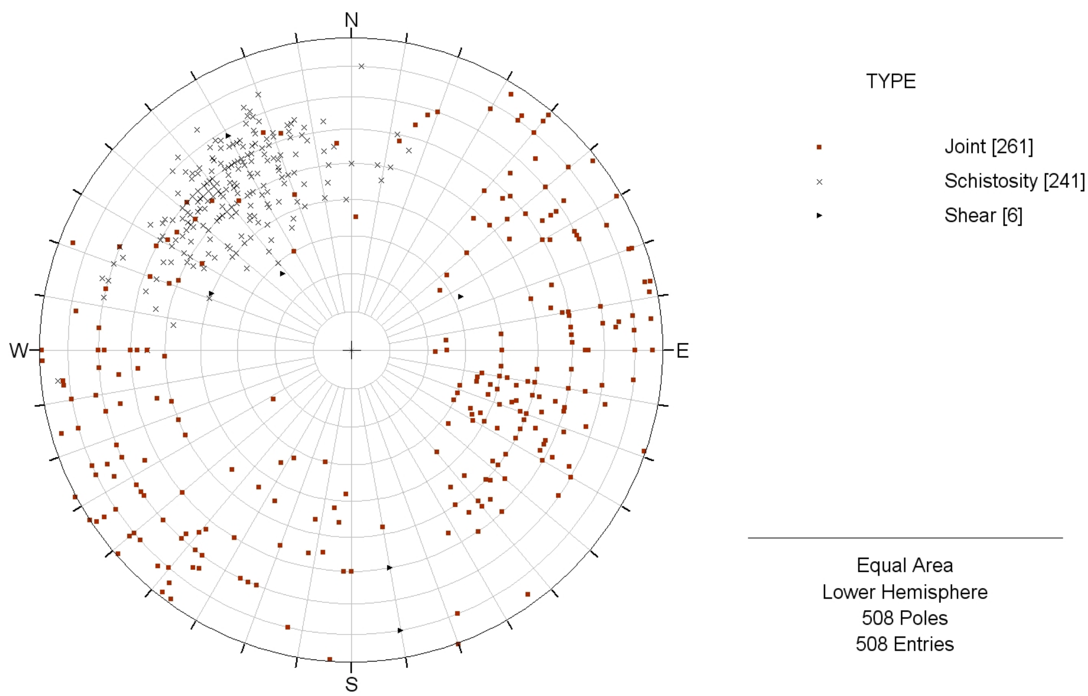


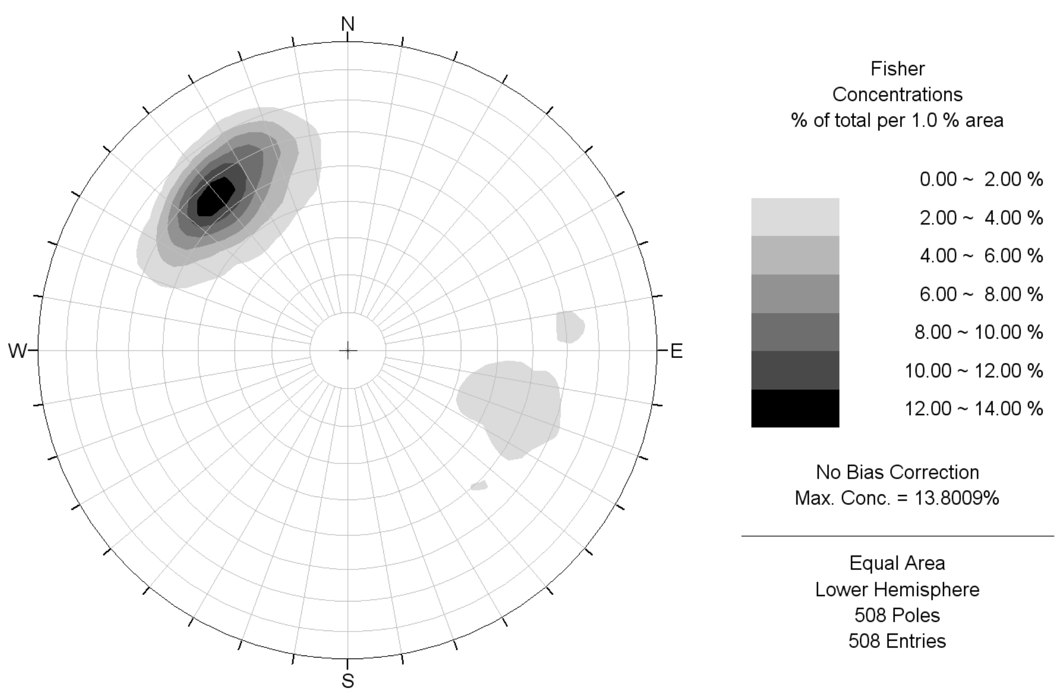
Project: Amethyst Hydro Project	Domain: 5
Major Structure Type: Schistosity	





Project: Amethyst Hydro Project	Domain: All
Major Structure Type: All	





Appendix F

F.1 Input Parameters for 3DEC model

	Domain 2			Domain 3			Domain 4			Domain 5		
	Schistosity	Joint Set 1	Joint Set 2	Schistosity	Joint Set 1	Joint Set 2	Schistosity	Joint Set 1	Joint Set 2	Schistosity	Joint Set 1	Joint Set 2
Jointset ID	1	2	9	1	2	9	1	2	9	1	2	9
Min Dip	26.7	29.5	25.7	26.7	29.5	25.7	26.7	29.5	25.7	26.7	29.5	25.7
Min D Direction	92.3	273	179.1	92.3	273	179.1	92.3	273	179.1	92.3	273	179.1
Max Dip	82.3	90	90	82.3	90	90	82.3	90	90	82.3	90	90
Max D Direction	178.2	352	271.4	178.2	352	271.4	178.2	352	271.4	178.2	352	271.4
Ave Dip	38.5	53.9	69	50	53.9	69	56.5	53.9	69	70	53.9	69
Ave D Direction	135	312.5	225.25	140	312.5	225.25	145	312.5	225.25	148	312.5	225.25
Ave D Direction Model corrected	339	156.5	69.25	344	156.5	69.25	349	156.5	69.25	352	156.5	69.25
Origin	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0
Spacing	0.15	0.8	1.1	0.15	0.8	1.1	0.15	0.8	1.1	0.15	0.8	1.1
Spacing Std Dev		0.25	0.4		0.25	0.4		0.25	0.4		0.25	0.4
Persistence	1	0.24	0.21	1	0.24	0.21	1	0.24	0.21	1	0.24	0.21
Number	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Bulk (K)	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3
Shear (G)	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
Sigma C Parallel	48	48	48	48	48	48	48	48	48	48	48	48
Sigma C Perpendicular	62.8	62.8	62.8	62.8	62.8	62.8	62.8	62.8	62.8	62.8	62.8	62.8
Density	2660	2660	2660	2660	2660	2660	2660	2660	2660	2660	2660	2660
Friction angle	48	48	48	48	48	48	48	48	48	48	48	48
Cohesion	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3

F.2 Input Parameters for 3DEC Stress Fields

Location		**Normal Stress (Mpa)**			**Shear Stress (Mpa)**			**sigma v / sigma h**	
Area	Structural Domain	sigmah cross x	sigmah long y	sigmav z	tau xy	tau zx	tau zy	Klong	Kcross
1	2	-0.9	-2.7	-3.7	0	-0.3	-2.26	1.2	4.6
2	3	-2.1	-1.9	-7.3	0	-0.5	-0.7	3.8	3.3
3	4	-3.2	-1.8	-9	0	-0.7	-0.1	5	2.6
4	5	-1.3	-1.7	-6	0	-0.6	-0.5	3.6	4.8
5	Not used	-0.8	-1.4	-2.5	0	-0.3	-0.6	1.8	3.1

F.3 RocData Input Parameters

Hoek Brown Classification
σ_{ci} = 40 MPa
GSI = 90
mi = 10
D = 0.8
Ei = 27000

Hoek Brown Criterion
mb = 5.5
s = 0.22
a = 0.50

Failure Envelope Range
Application = Tunnel
σ_3 max = 2.64 MPa
Unit Weight = 0.026 MN/m3
Tunnel Depth = 200 m

Mohr-Coulomb Fit
c = 3.33 MPa
phi = 47.96 degrees

Rock Mass Parameters
σ_t = -1.59 MPa
σ_c = 18.75 MPa
σ_{cm} = 19.04 MPa
Erm = 14100 MPa

F.4 Code Files

Note – same code for all domains, but highlighted areas changed depending on the individual domain properties

```
new

;form block

poly brick -13,13 -10,10 -13,21
```

```
pl bl colorby material
pl reset
pl set dip 70 dd 200
tunnel radial region 1 &
 a (-1.75,-10,0.00) (-1.75,-10,1.75) (-1.52,-10,2.62) &
(-0.88,-10,3.26) (0.00,-10,3.5) (0.88,-10,3.26) &
(1.52,-10,2.62) (1.75,-10,1.75) (1.75,-10,0.00) &
 b (-1.75,10,4.43) (-1.75,10,6.18) (-1.52,10,7.05) &
(-0.88,10,7.69) (0.00,10,7.93) (0.88,10,7.69) &
(1.52,10,7.05) (1.75,10,6.18) (1.75,10,4.43)
; cut with joints/schistosity
jset dip 38.5 dd 339 spac 0.15 num 1000 org 0,0,0 p 1 id 1
jset dip 53.9 dd 156.5 spac 0.8 0.25 num 1000 org 0,0,0 p 0.24 id 2
jset dip 69 dd 069.25 spac 1.1 0.4 num 1000 org 0,0,0 p 0.21 id 9
;assign material number
change mat=1
;change material properties
prop mat=1 bcohesion 3.33 phi 48 btension 1.59 bulk 21.3e9 density 2650 g 18.4e9
prop jmat=1 jkn 132e6 jks 202e6 coh 1e9 ten 1e9
prop jmat=2 jkn 132e6 jks 202e6 coh 1e9 ten 1e9
prop jmat=9 jkn 132e6 jks 202e6 coh 1e9 ten 1e9
save c:/users/ems81/documents/save_files/Domain_2_geometry.sav
;initial conditions
```

```
grav 0, 0, -10.0
insitu stress -0.9e6, -2.7e6, -3.7e6, 0, -0.3e6, -2.26e6
;boundary conditions
apply xvel 0 range x -13.1,-12.9
apply xvel 0 range x 13.1,12.9
apply yvel 0 range x -13.1,-12.9
apply yvel 0 range x 13.1,12.9
apply zvel 0 range x -13.1,-12.9
apply zvel 0 range x 13.1,12.9
apply xvel 0 range y -10.1,-9.9
apply xvel 0 range y 10.1,9.9
apply yvel 0 range y -10.1,-9.9
apply yvel 0 range y 10.1,9.9
apply zvel 0 range y -10.1,-9.9
apply zvel 0 range y 10.1,9.9
apply xvel 0 range z -13.1,-12.9
apply xvel 0 range z 20.9,21.1
apply yvel 0 range z -13.1,-12.9
apply yvel 0 range z 20.9,21.1
apply zvel 0 range z -13.1,-12.9
apply zvel 0 range z 20.9,21.1
hist unbalanced
hist zdisp 0,0,21
```

```
hist ty 1

pl hist 1

solve

save c:/users/ems81/documents/save_files/Domain_2_block.sav

reset disp

remove region 1

;soften joints

prop jmat=1 jkn 132 jks 202 coh 3.3e6 ten 15e6

prop jmat=2 jkn 132 jks 202 coh 3.3e6 ten 1e5

prop jmat=9 jkn 132 jks 202 coh 3.3e6 ten 1e5

save c:/users/ems81/documents/save_files/Domain_2_excavated.sav
```

F.5 Model Outputs

F.5.1 Domain 2

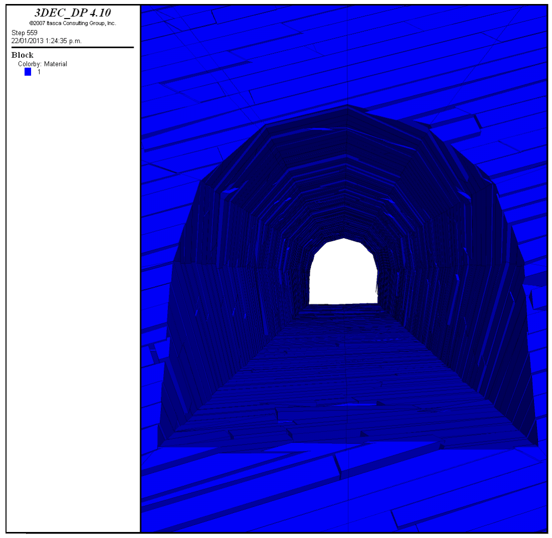


Figure F-1: Domain 2 model step 559

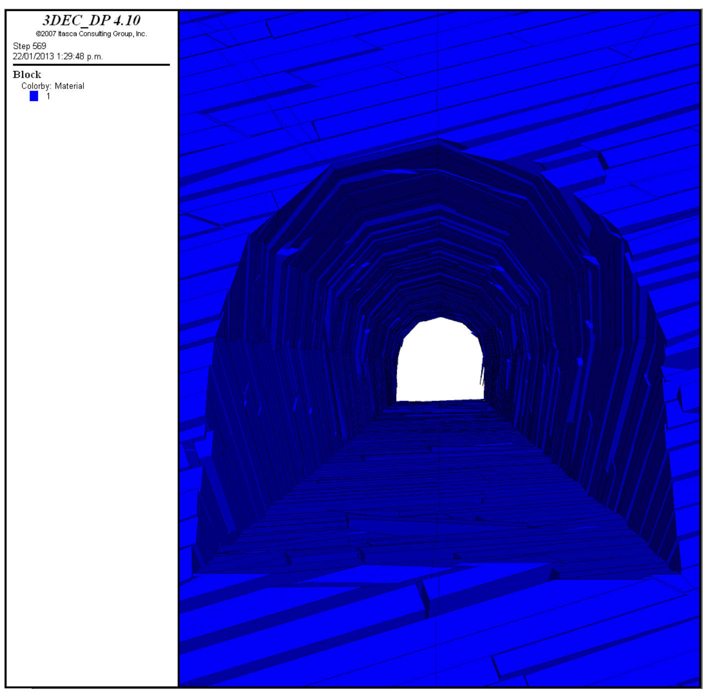


Figure F-2: Domain 2 model step 569

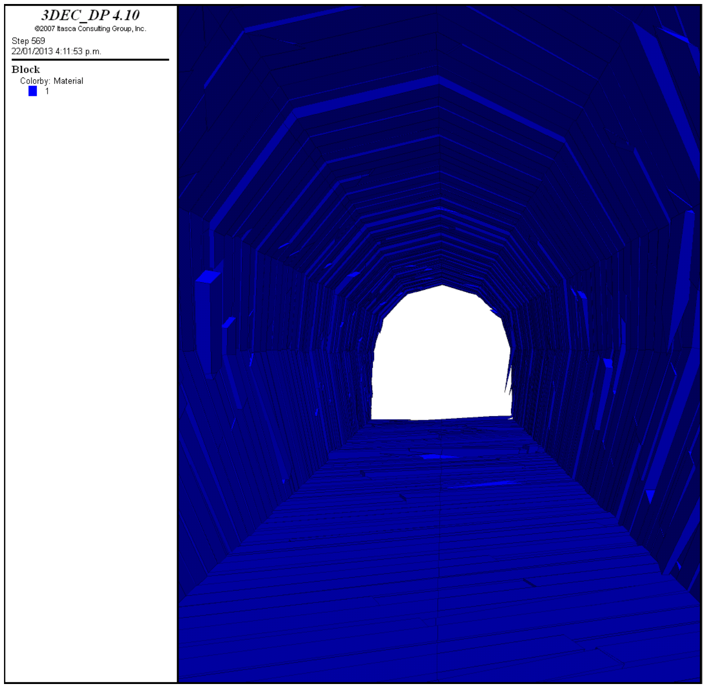


Figure F-3: Domain 2 close up.

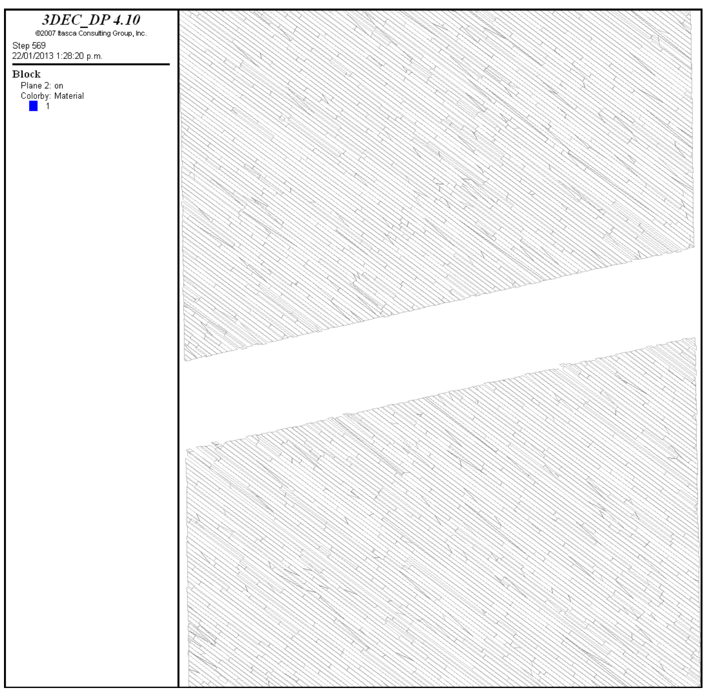


Figure F-4: Domain 2 longitudinal cut away.

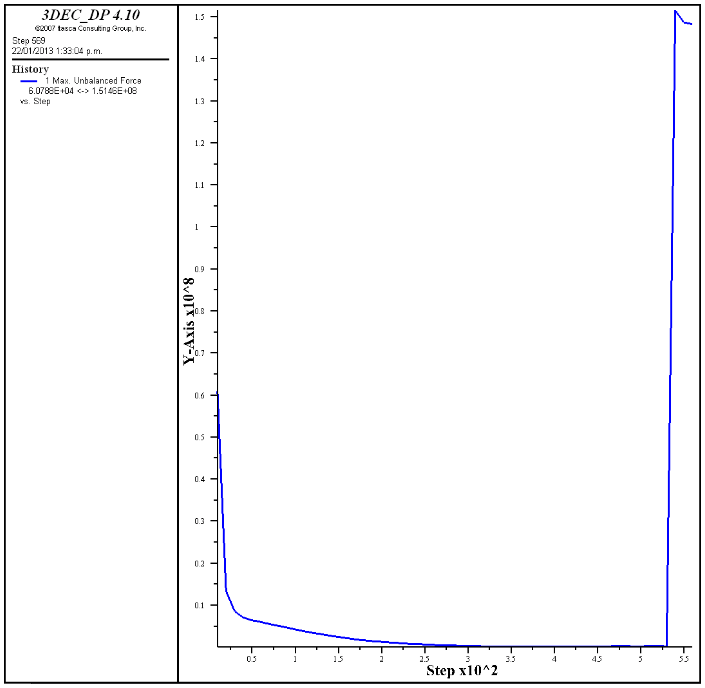


Figure F-5: Domain 2 history of unbalanced forces.

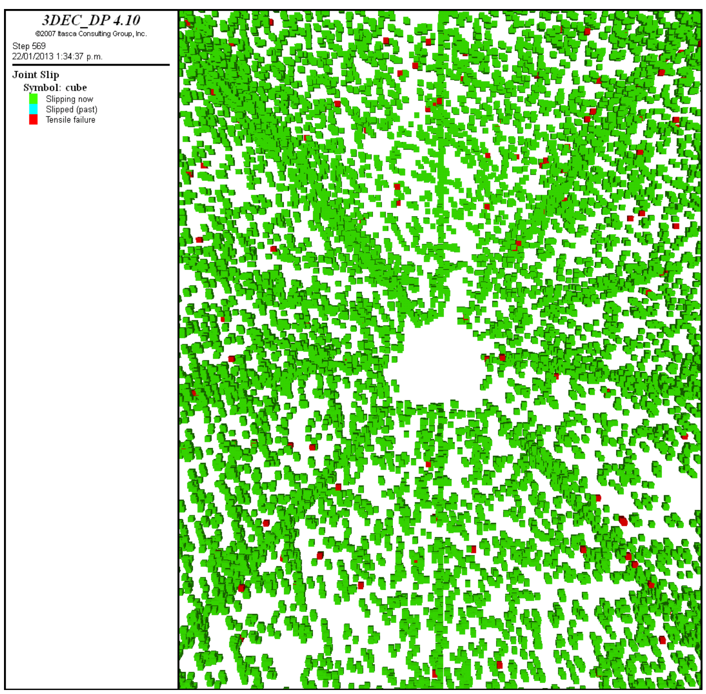


Figure F-6: Domain 2 joint slip.

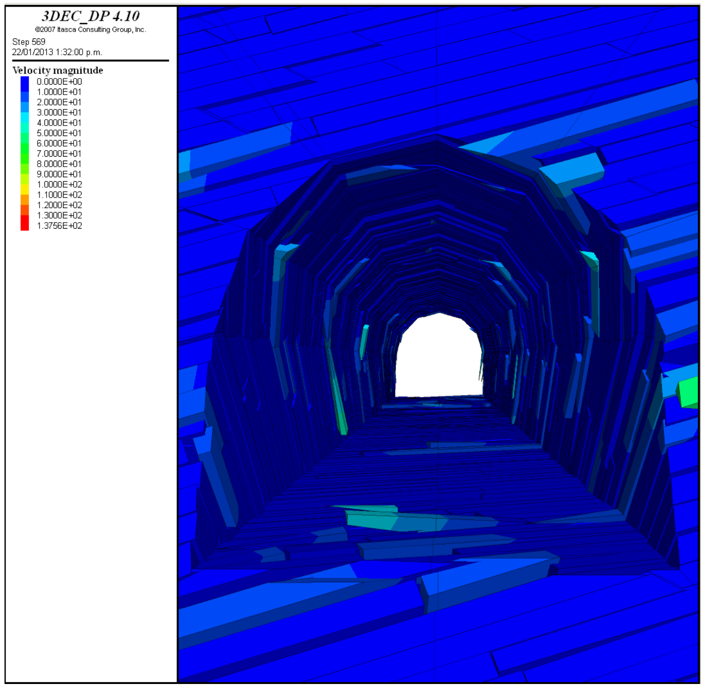


Figure F-7: Domain 2 contoured velocity.

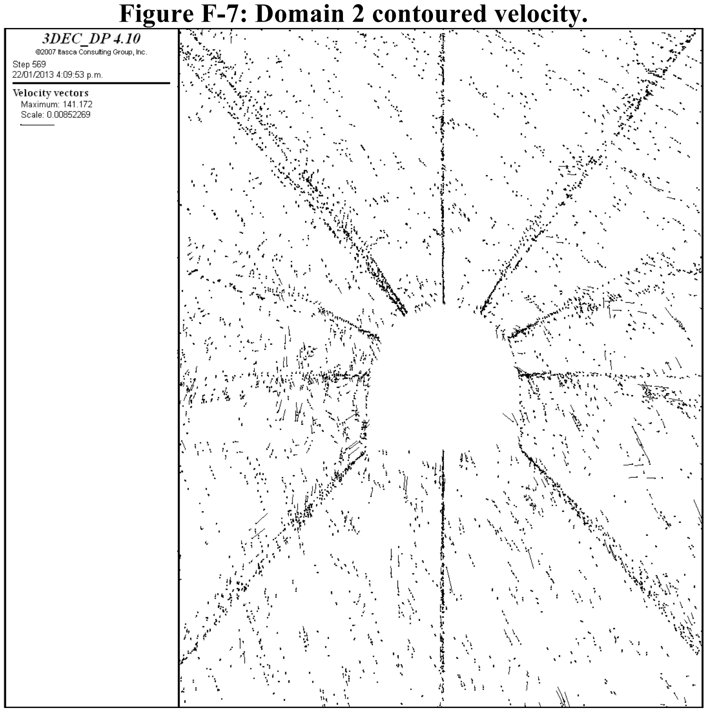


Figure F-8: Domain 2 velocity vectors.

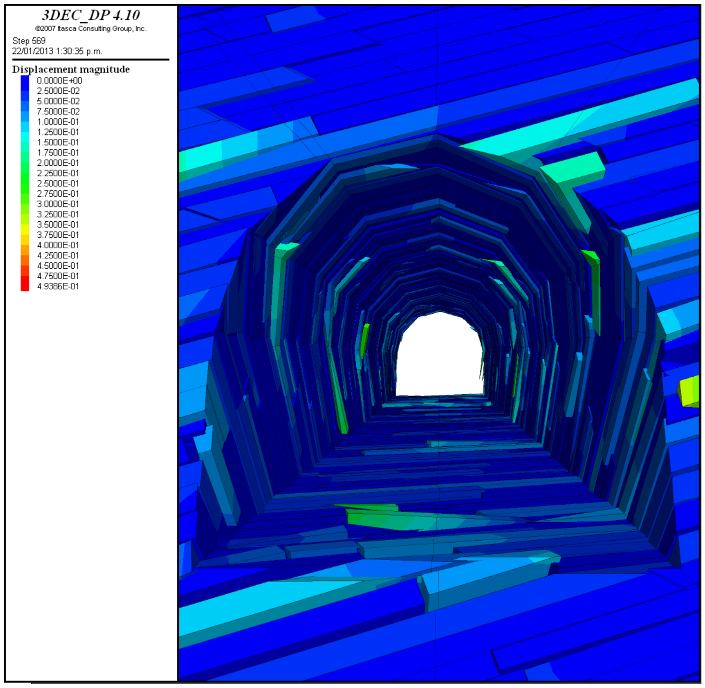


Figure F-9: Domain 2 contours of displacement.

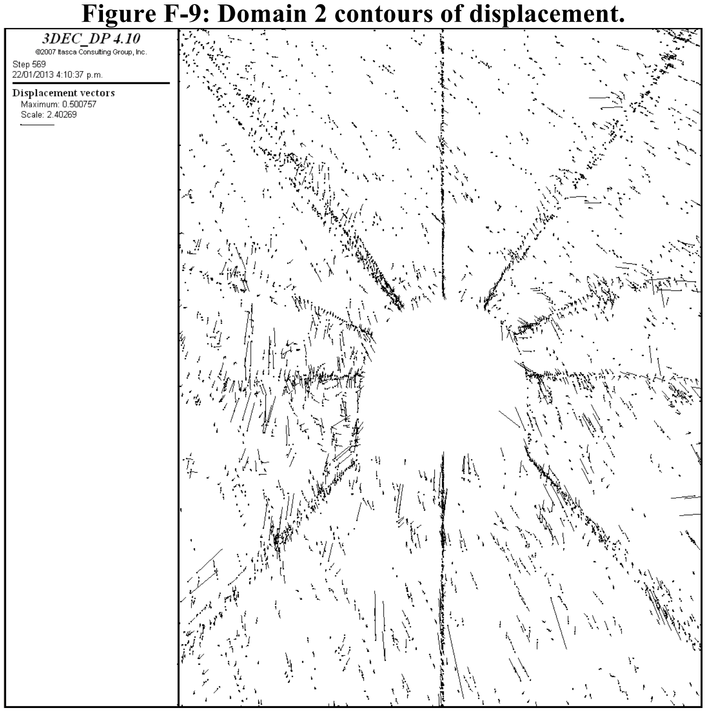


Figure F-10: Domain 2 displacement vectors.

F.5.2 Domain 3

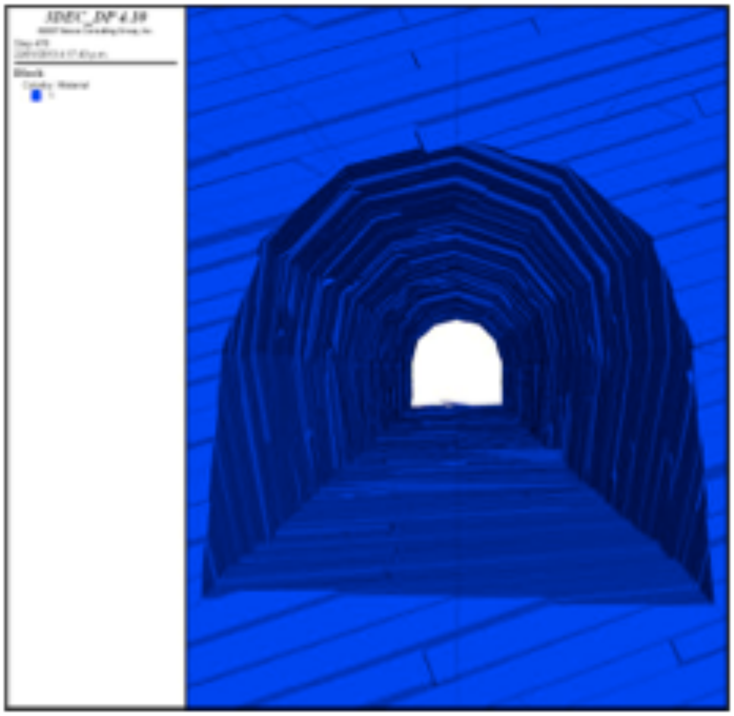


Figure F-11: Domain 3 step 478.

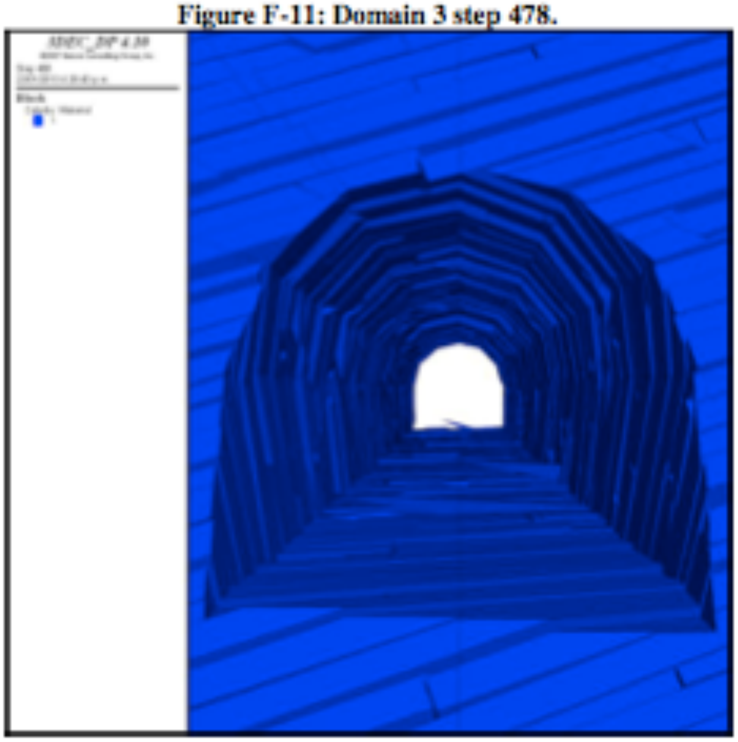


Figure F-12: Domain 3 step 488.

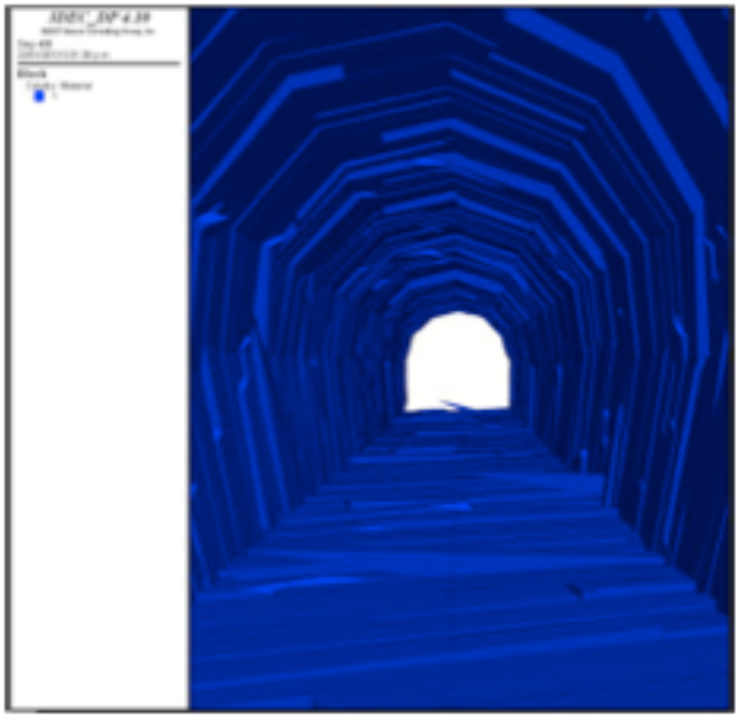


Figure F-13: Domain 3 close up.

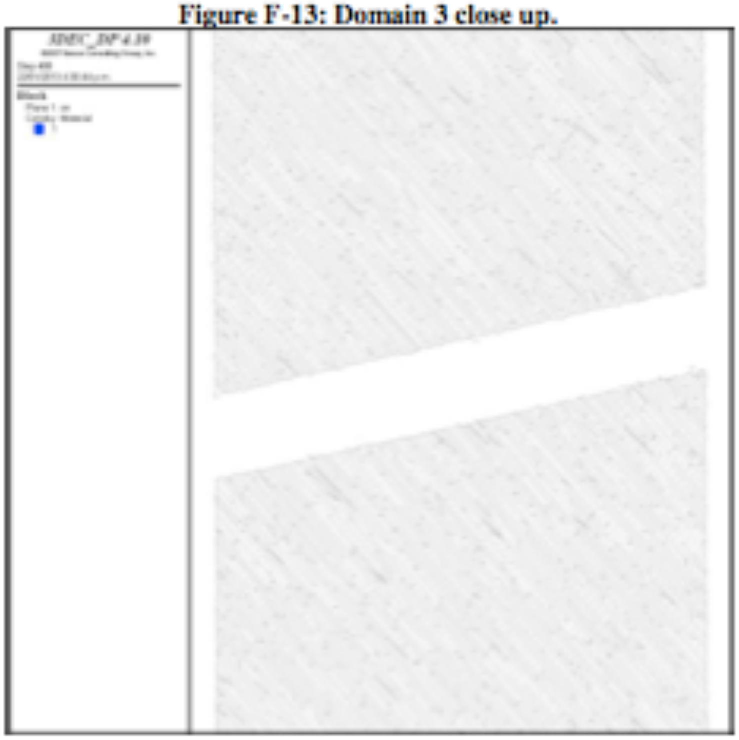


Figure F-14: Domain 3 longitudinal cut away.

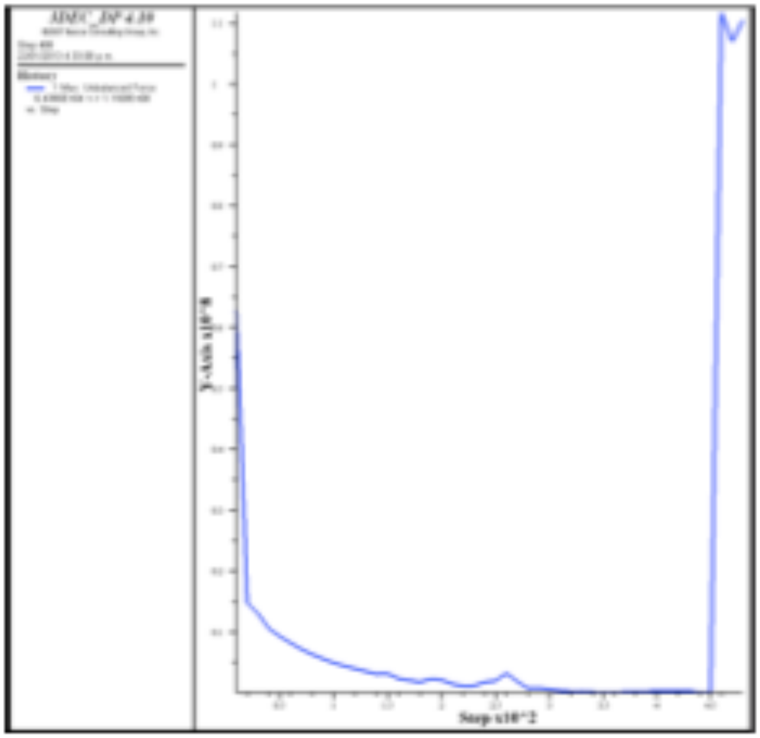


Figure F-15: Domain 3 history of unbalanced forces.

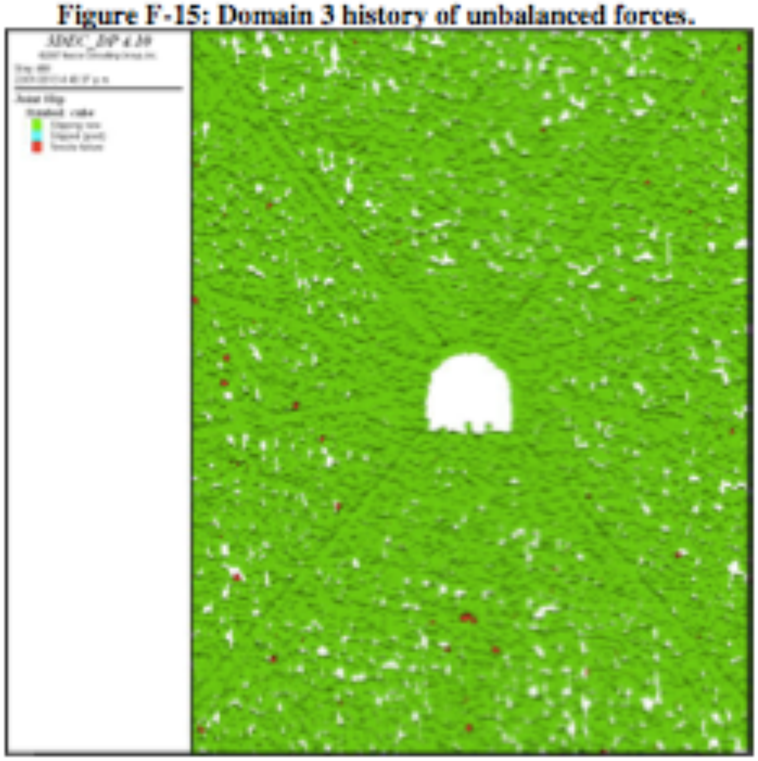


Figure F-16: Domain 3 joints slip.

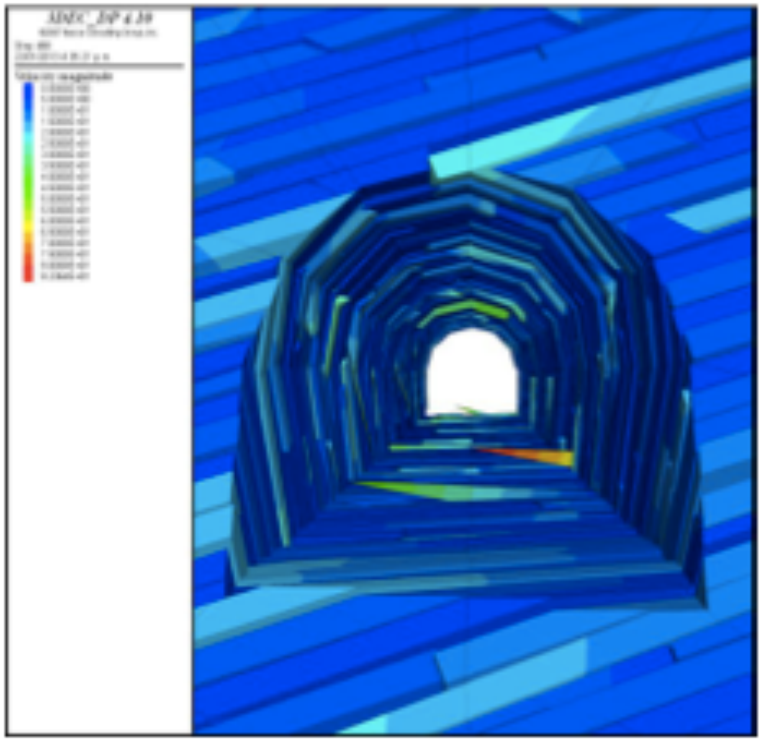


Figure F-17: Domain 3 block velocity contours.

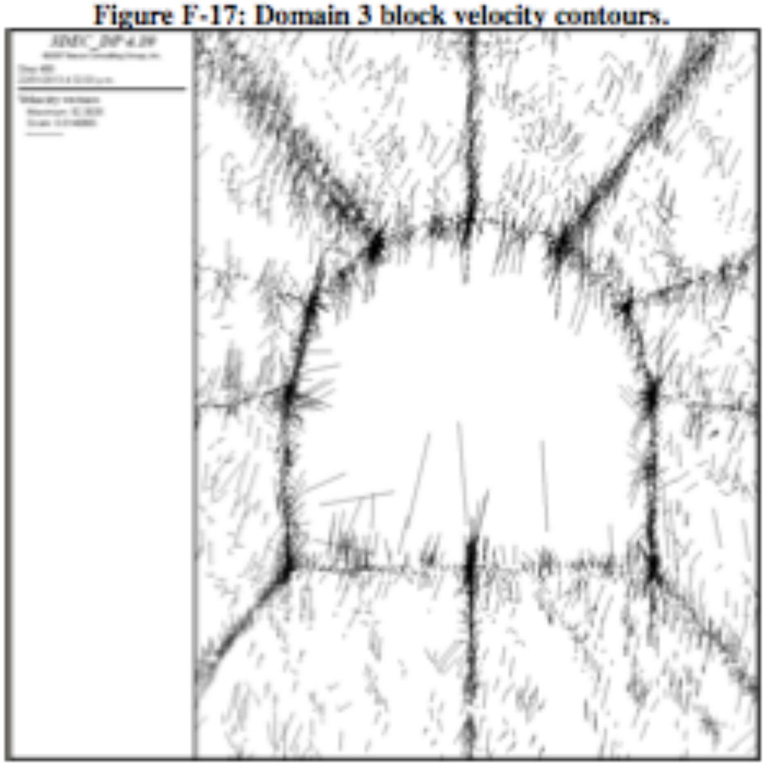


Figure F-18: Domain 3 block velocity vectors.

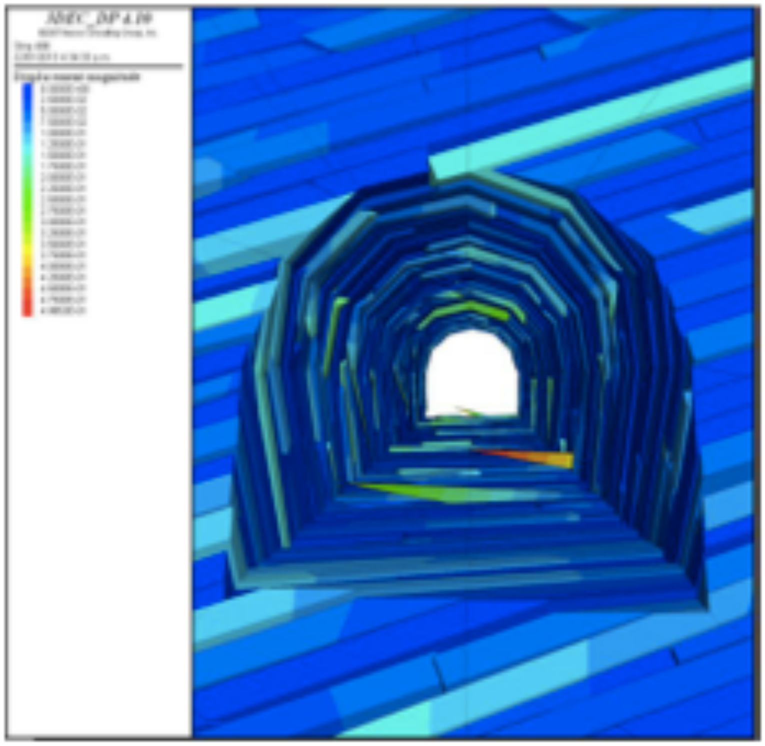


Figure F-19: Domain 3 displacement contours.

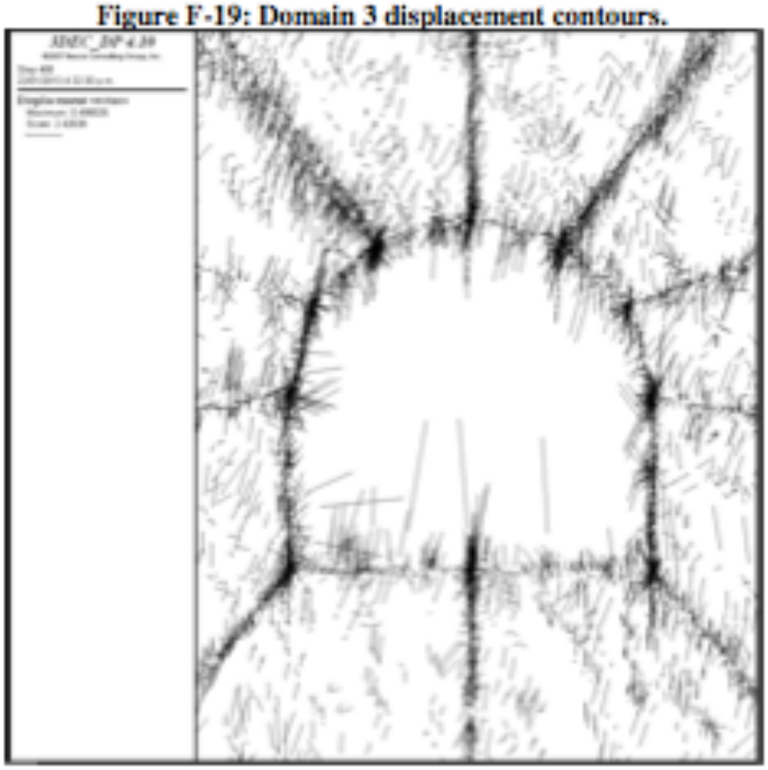


Figure F-20: Domain 3 displacement vectors.

F.5.3 Domain 4

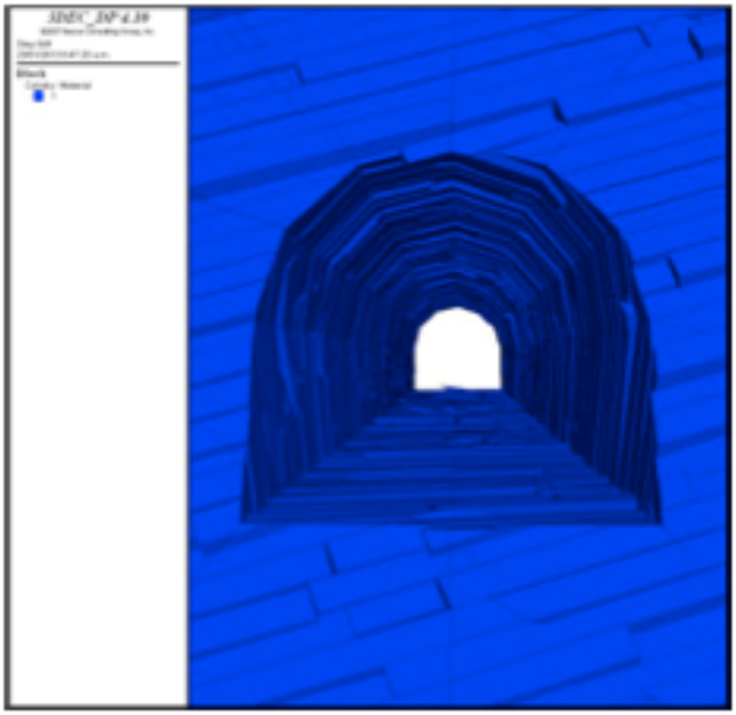


Figure F-21: Domain 4 step 549.

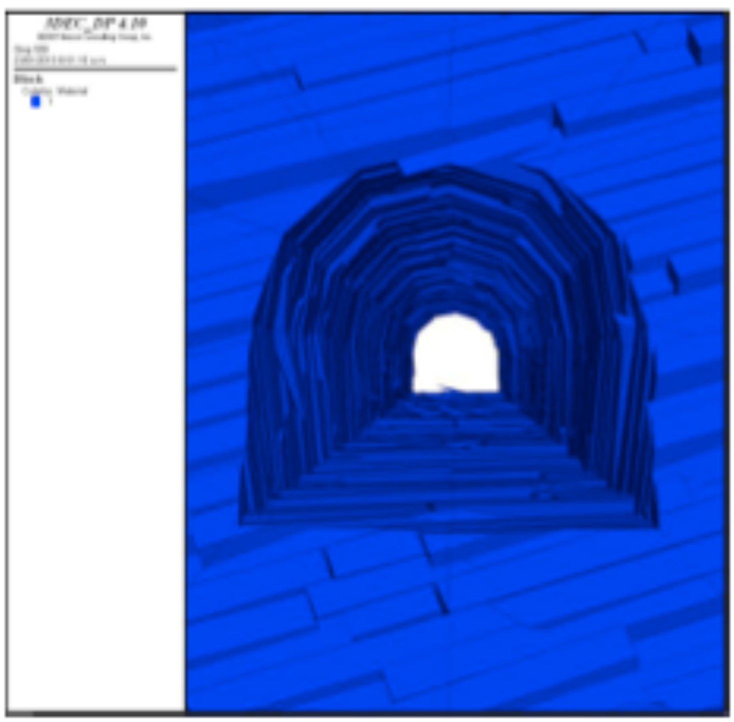


Figure F-22: Domain 4 step 559.

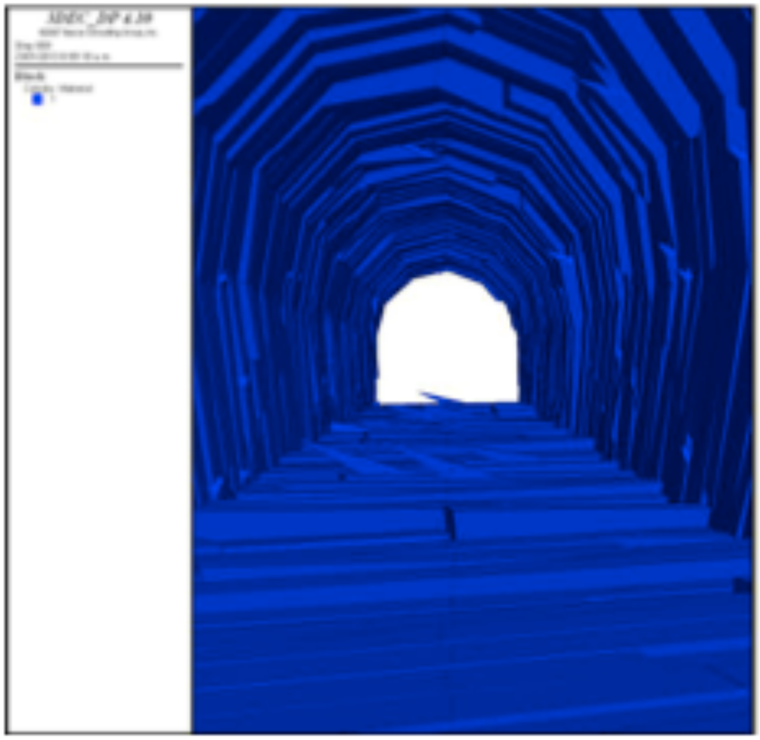


Figure F-23: Domain 4 close up.

Figure F-24: Domain 4 longitudinal cut away.

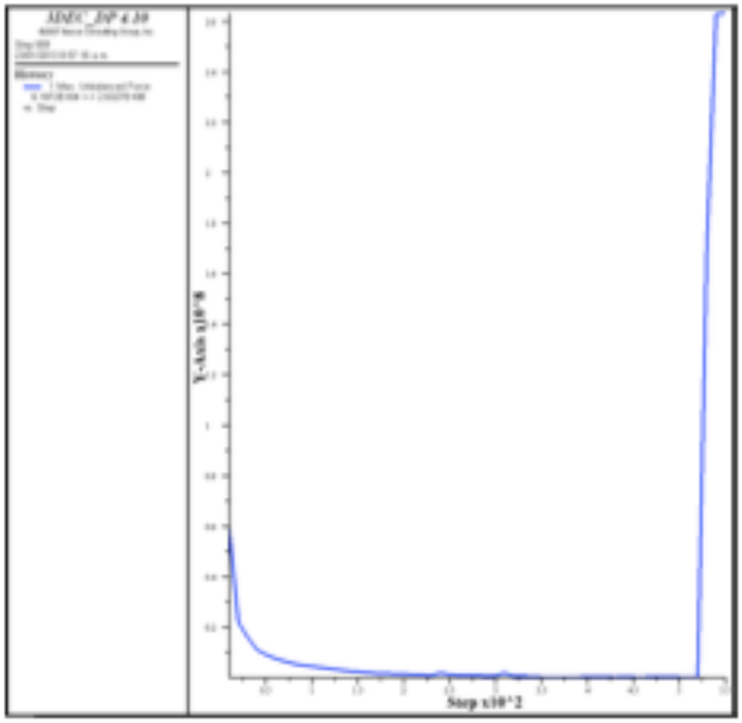


Figure F-25: Domain 4 history of unbalanced forces.

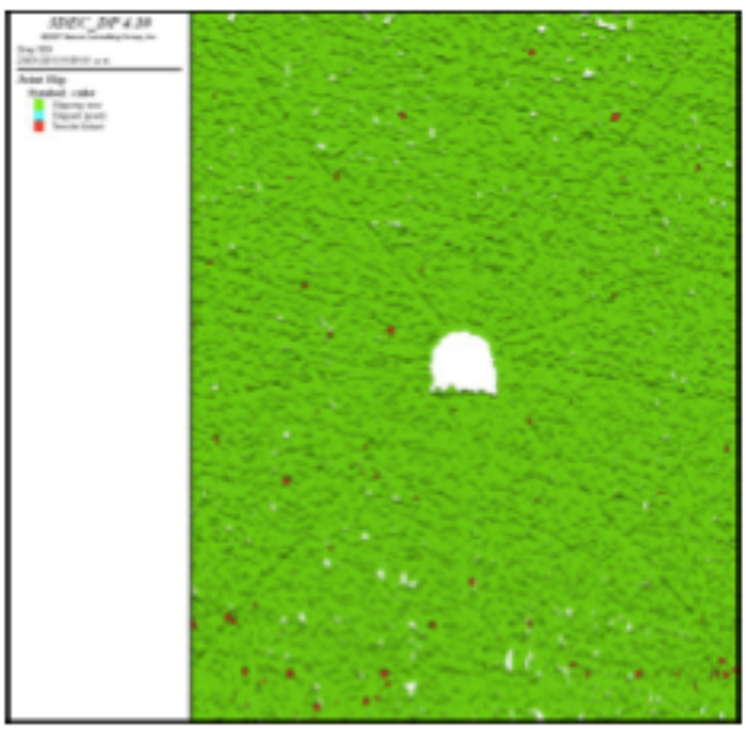


Figure F-26: Domain 4 joint slip plot.

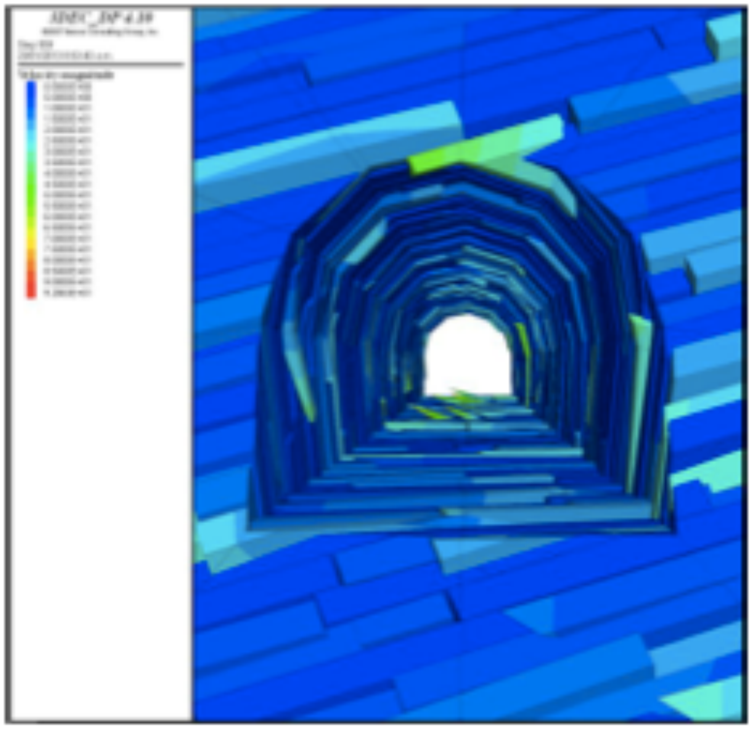


Figure F-27: Domain 4 velocity contours.

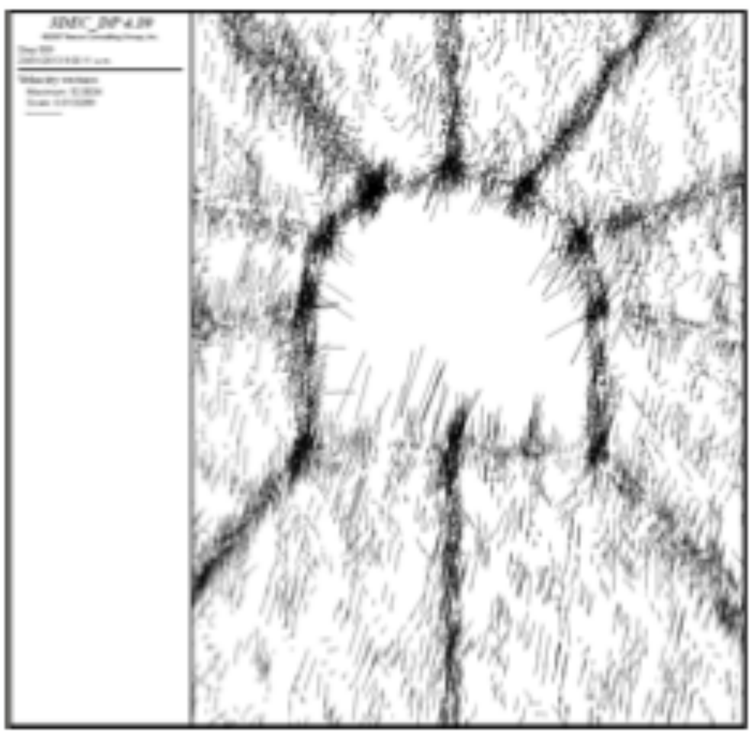


Figure F-28: Domain 4 velocity vectors.

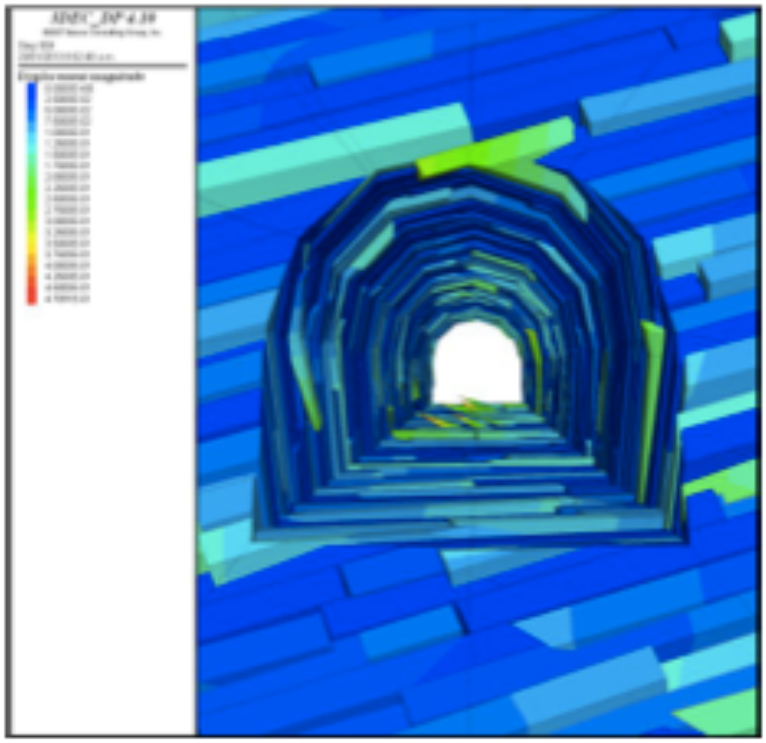


Figure F-29: Domain 4 displacement contours.

Figure F-30: Domain 4 displacement vectors.

F 5.4 Domain 5

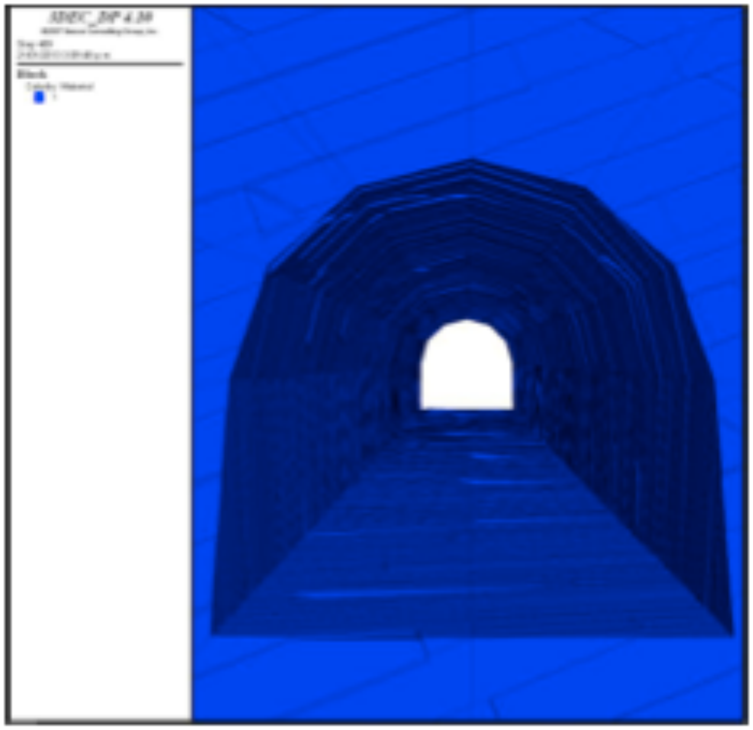


Figure F-31: Domain 5 step 489.

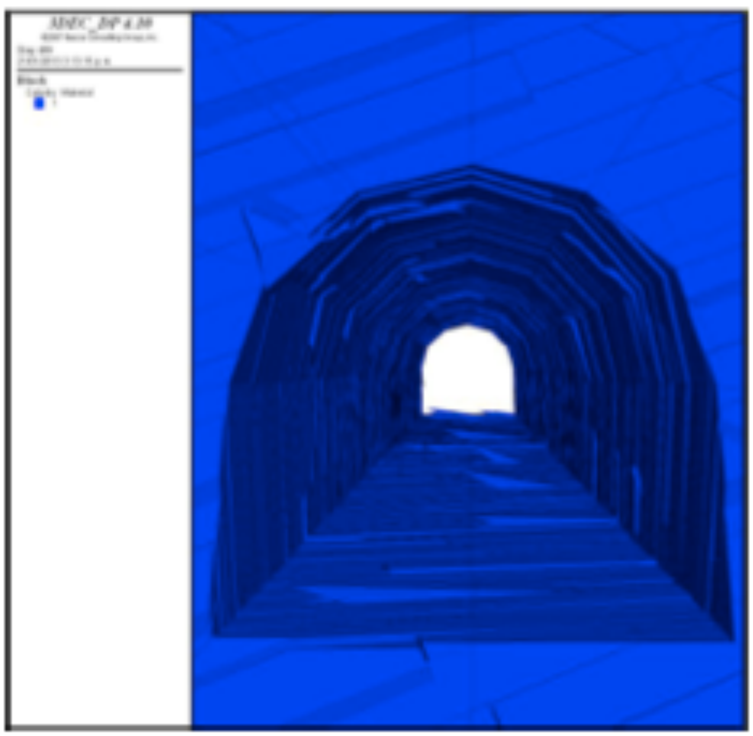


Figure F-32: Domain 5 step 499.

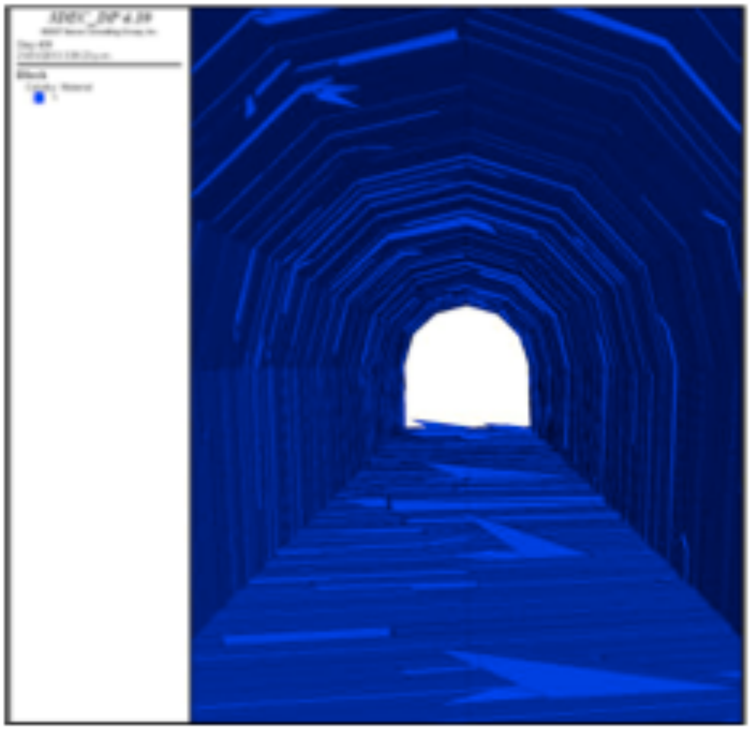


Figure F-33: Domain 5 close up.

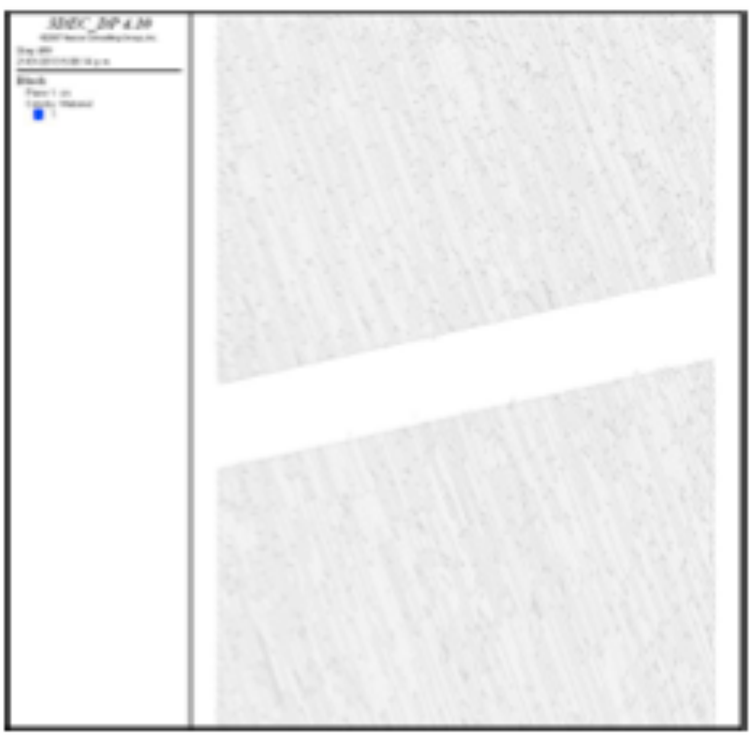


Figure F-34: Domain 5 longitudinal cut away.

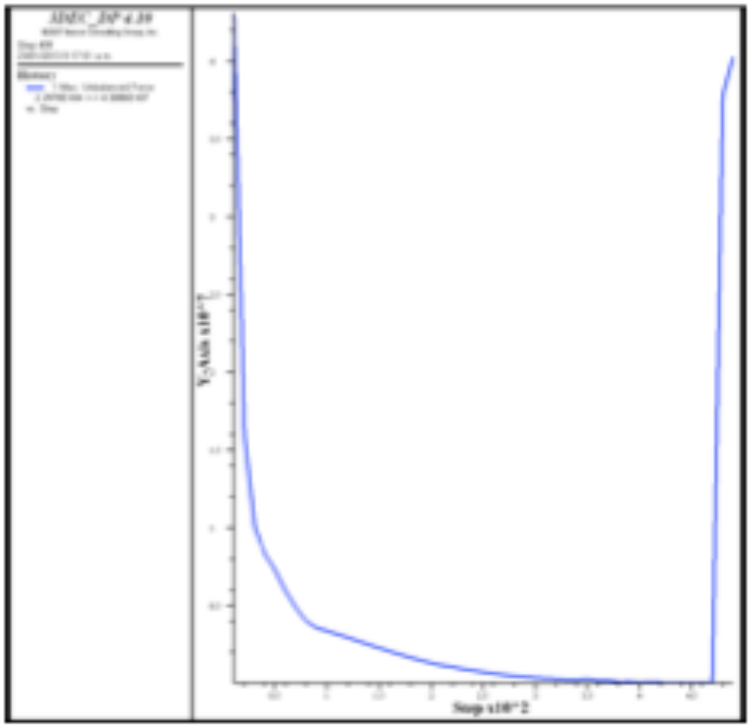


Figure F-35: Domain 5 history of unbalanced forces.

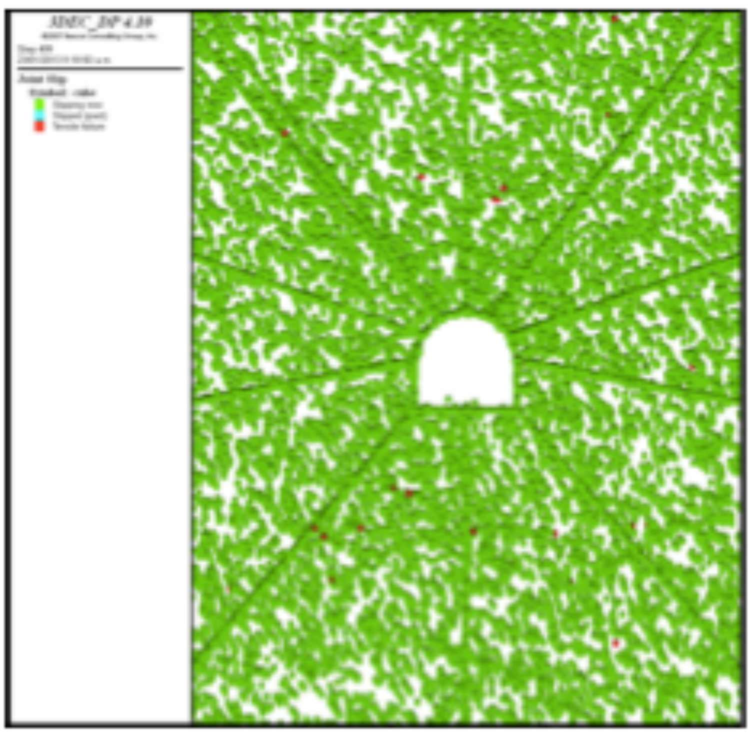


Figure F-36: Domain 5 joint slip.

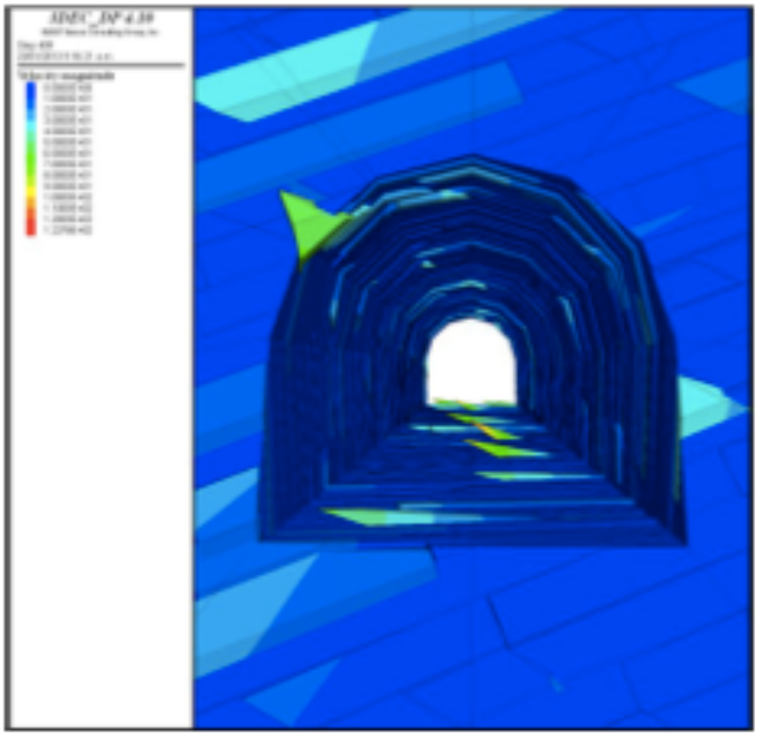


Figure F-37: Domain 5 velocity contours.

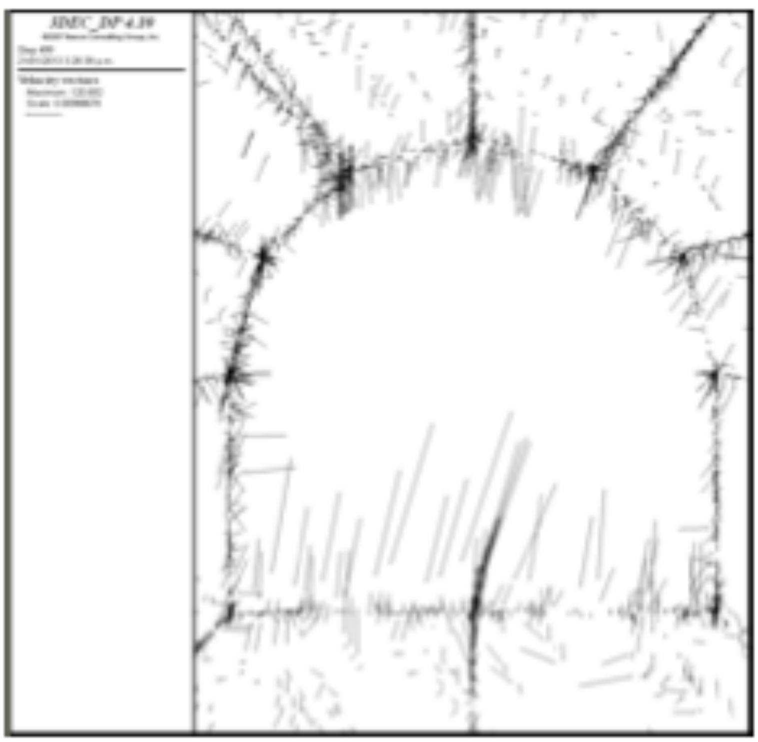


Figure F-38: Domain 5 velocity vectors.

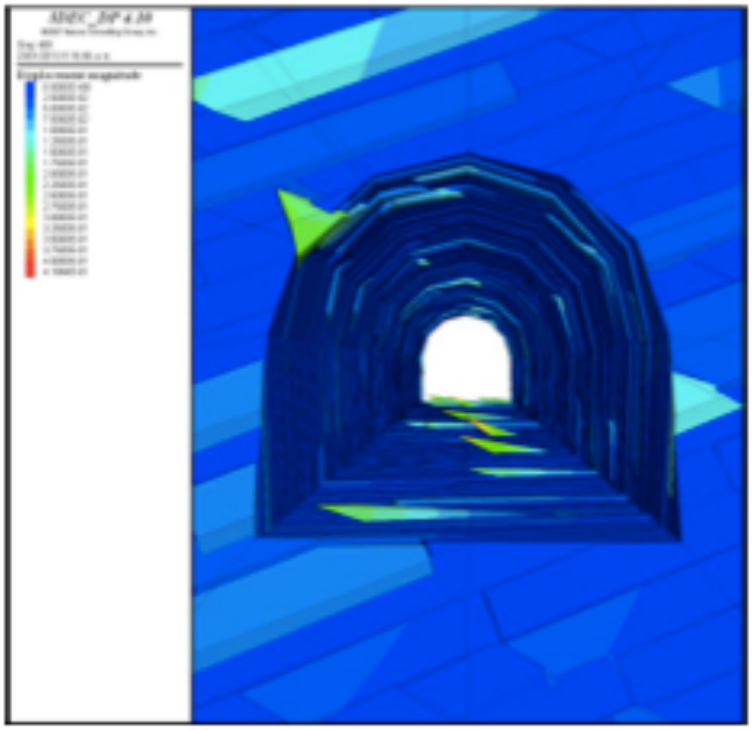


Figure F-39: Domain 5 displacement contours.

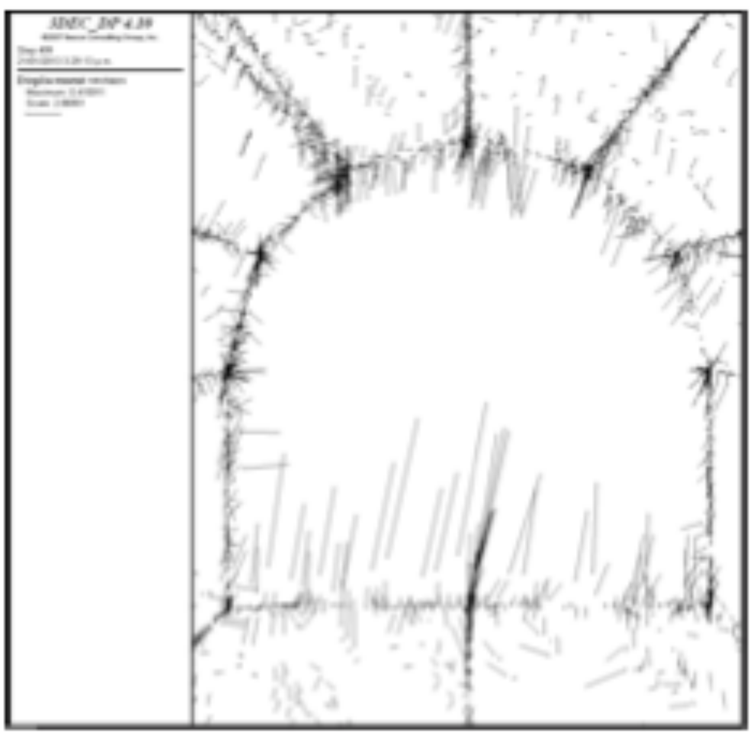


Figure F-40: Domain 5 displacement vectors.